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THEOBROMA CACAO

OR

COCOA,

ITS BOTANY, CULTIVATION, CHEMISTRY AND DISEASES

BY

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PREFACE.

CACAO is a product which, for many years, has been cultivated in parts of tropical America, the East and West Indies, Africa, and in numerous other islands and territories in the tropical zone. Much botanical and experimental work has been done in the West Indies, West Coast of Africa, Cameroon, Samoa, Madagascar, Central and South America, etc., and the main object in this publication is to present the results obtained in cacao-growing countries in a synoptical form and to bring them into line with the research done in Ceylon during the last few years.

The results obtained at the Experiment Station, Peradeniya, have all been dealt with in a fragmentary manner in my annual reports, circulars, lectures, and articles in *The Tropical Agriculturist* and are now incorporated in book form, together with the accounts published on similar subjects by more experienced men in various parts of the world. Analyses of Ceylon-grown cacao plants, by Messrs. M. Kelway Bamber and A. Bruce are, by their permission included. The book is imperfect and incomplete; it would have been much more so had frequent reference not been possible to the results published by Preuss, Wohltmann, Jumelle, Harrison, Hart, and other workers in tropical America and the East and West Indian islands.

This publication is therefore presented more as a compilation than as one containing the results of the writer's research; it is hoped that it will serve as a basis for future experiments and as a means of spreading useful information.

At the present time the principles of manuring, budding, grafting, pruning, seed selection, and plant sanitation operations, in relation to cacao, are neither fully understood nor universally practised, yet much might be done to improve the prospects of this comparatively old cultivation; cacao is a product which undoubtedly lends itself to improvement in countless ways, much more so than

others largely cultivated in the tropics. The fact that cacao is a forest plant, capable of being cultivated with success in association with other tree forms, especially those belonging to the Leguminosæ and numerous rubber-producing types, has awakened considerable interest in this product, and for these reasons the points referred to have been given a prominent place in the present work.

Frequent reference has been made to Preuss's *Expedition nach Central und Südamerika*; Jumelle's *Le Cacaoyer;* Hart's *Cacao*; Olivieri's *Treatise on Cacao*; Wohltmann's work on cacao in Samoa; to the Bulletins, Circulars, and Reports issued by the Botanic Departments at Kew, the West Indies, Ceylon, and West Africa; the Imperial Institute, London; *The Tropical Agriculturist; Journal D' Agriculture Tropicale*; *Der Tropenpflanzer*: *Revue des Cultures Coloniales* and *L'Agriculture Pratique des Pays Chauds*. The results recorded in these journals and publications have been necessarily given in a very brief form, and to them the present volume owes its existence.

I desire to acknowledge the assistance I have obtained in this work, from Dr. J. C. Willis, Messrs. E. E. Green, M. Kelway Bamber, A. Bruce, H. F. Macmillan, J. K. Nock, Ivor Etherington, and Marian Wright; also to numerous planters in Ceylon and to Officials in the Agricultural and Botanic Departments in various parts of the world, for the information quoted in the various sections. The index has been kindly prepared by Mr. Ivor Etherington.

H. W.

12th. January, 1907.

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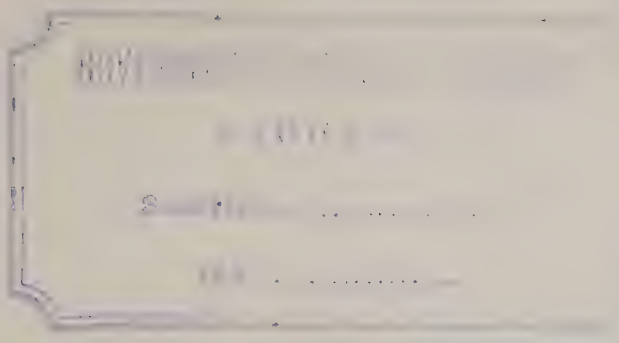

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CHAPTER I.

NOTES ON THE HISTORY OF CACAO.

General.

IN compiling this account of the history of cacao in parts of tropical America, Africa, the East and West Indies etc., much difficulty has been experienced in obtaining information of an interesting and useful character: reference should be made to the sources mentioned if more detailed particulars are required by the reader.

The cacao tree is a product of the forests of Central America * and though the qualities of its seeds were only first made known in Europe in 1519, the tree was, previous to the 16th century, cultivated by the Mexicans. Numerous interesting legends and accounts of ceremonial occasions associated with cacao have been contributed by Herrera, Quatzalcault, Rozière, Montezuma, Gallais, Humboldt and others.

The fruits were highly prized by the Mexicans: according to Herrera, only the lords and brave warriors had the right to use them. The Mexicans called the tree Cacao-quahuitl.

The seeds were first used in conjunction with powdered maize, sugar, and other foods; they also served as the equivalent of money in commerce. Their bitterness when used alone as food was soon overcome by the experimental admixture of requisite quantities of cayenne pepper, cinnamon or vanilla, according to the tastes of the favoured ones; finally a form of chocolate was made and used largely in Spanish-America which subsequently found its way to Spain, Italy, and France where manufactories became established.

The cultivation of cacao outside tropical America was rapidly taken up by the people in the West Indian islands, and even as early as 1727 diseases became significant and their ravages on cultivated cacao were very disastrous. The East Indian possessions took up the cultivation at a later date, many people obtaining their supplies of seeds and plants from the West Indian islands where successful results had been obtained.

* Henri Jumelle, Le Cacaoyer, sa Culture et son Exploitation dans tous les Pays de Production; Paris, 1900.

At the present time cacao is largely grown in tropical America, Africa, the West and East Indies, and many other islands and territories in the tropical zone. The distribution of seeds through Kew and other agencies, and from botanic departments all over the tropical world, is still carried out frequently and often on an extensive scale.

Cacao in the West Indies.

The West Indian islands have long been known for the cacao which they export, and the distribution of seeds and plants therefrom to various parts of the world has been steadily going on for many years.

The output of cacao from these islands has considerably increased during the last few years, especially from Trinidad, Grenada, Jamaica, St. Lucia, and Dominica. There are also indications that the increase will be maintained, several thousands of plants being yearly issued to local planters by the various Botanic Gardens and the Imperial Department of Agriculture. During the last five years, "*the increase in output from these islands has been something like 50 per cent.,—from 337,431 cwt. in 1898 to 495,653 cwt. in 1902. The industry has grown to such an extent, especially in some of the islands, that cacao occupies a very important place in the list of exports. Thus, the value of the cacao annually exported from Trinidad now exceeds £1,000,000, while from Grenada £250,000 worth is exported. Though Trinidad and Grenada are the two most important producers of cacao in the West Indies, there is a continually increasing export from Jamaica, which reached the value of £84,000 in 1901-02, while in 1900 the exports of cacao from St. Lucia formed 17 per cent. of the total exports. Considerable quantities of cacao are also shipped from Dominica, St. Vincent, and British Guiana; Montserrat and St. Kitts-Nevis also produce small amounts." Respecting the quality of the cacao shipped from the West Indies the same review states that that from Trinidad fetches the highest price, the bean being said to be "the finest and best flavoured." The same authority writing in 1904 stated that the London prices varied from 65s. to 80s. per cwt. for Trinidad cacao. "Grenada cacao, although it does not obtain quite as high a price, has a good and regular flavour, and the crop is eagerly bought up in British and American markets. Other cacaos from the West Indies—those from Jamaica, Dominica, and St. Lucia—are generally classed together in the market reports."

Trinidad.—This island had, in 1900, from 200,000 to 225,000 acres† of land under cacao cultivation, and the industry is still viewed with favour especially where the cacao can be grown in association with rubber-producing trees.

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* Agr. News, Vol. III., No. 64, 1904, and West Indian Bulletin, Vol. V., No. 2, Barbadoes.

† Tropical Agriculturist, Colombo, 1900-01.

The following table gives the approximate quantities of cacao exported from Trinidad, most of which is the actual produce of that colony :—

EXPORTS OF CACAO FROM TRINIDAD.

Years.		Quantity in lb.	Years.		Quantity in lb.
1821	...	1,214,094	1897	...	23,840,665
1851	...	5,008,923	1898	...	24,340,960
1880	...	11,475,530	1901	...	21,454,184
1893	...	19,106,553	1902	...	33,268,490
1894	...	21,608,384	1903	...	27,664,840
1895	...	29,458,813	1904	...	41,790,080
1896	...	23,481,848			

The importance of Grenada and St. Lucia as cacao-producing countries can be judged by a reference to the details of export given elsewhere.

MONTSERRAT.—Cacao has been tried at Montserrat, and though the plants appear to have suffered from the effects of very dry weather* some of them flowered for the first time in 1904. Most of the trees were reported to be about 4 feet in height in 1904. Quite recently the cacao industry has received the attention of the authorities, and the Montserrat Company has taken in hand the restoration and extension of a small plantation at Woodlands, where it is hoped successful results will be obtained. It appears that a mistake has probably been made in the past in Montserrat, and districts at low elevations are now to be attended to in preference to those at high altitudes.

DOMINICA.—This country is rapidly coming into prominence in connection with the numerous manurial experiments being carried out by the West Indian botanic authorities. The following table of exports will serve to show the importance of Dominica as a cacao-growing country :—

Year.		Export.	Year.		Export.
1894-5	...	851,334 lb.	1899-1900	...	968,740 lb.
1895-6	...	499,113 ,,	1900-1901	...	992,586 ,,
1896-7	...	946,393 ,,	1901-1902	...	1,052,693 ,,
1897-8	...	885,024 ,,	1902-1903	...	1,309,577 ,,
1898-9	...	1,082,851 ,,	1903-1904	...	1,285,245 ,,

ST. KITTS-NEVIS.—According to one report† the growth of cacao on a commercial scale may be said to have been begun in this island on at least three estates, and on each place the young plants are showing satisfactory progress, and the cultivation is gradually but steadily increasing in area. The seed was mainly obtained from Dominica.

* Reports on the Botanic Station and Experiment Plots, Montserrat, W. Indies, 1904-05.

† Reports of the Botanic Stations and Agricultural Education, St. Kitts-Nevis ; 1904-05.

Jamaica.—According to Fawcett*, the planters of Jamaica, though they consider the cacao industry as being of considerable importance, do not regard it, as do the cultivators in Trinidad and Grenada, as one of their great industries; it is, at present, rather a subsidiary industry in that country.

St. Vincent and Bahama.—The report previously referred to states that "of all cacao-producing islands in the West Indies, St. Vincent is the only one unable to show a decided advance. This, of course, is due to the hurricane of 1898. In 1897 the exports of cacao were of the value of £4,514; two years later they were worth only £116." In the Bahamas there is practically no cacao under cultivation.

Cacao in Central America.

Considerable attention is paid to the cultivation of cacao in parts of Guatemala where conditions are favourable for this product, on account of the volcanic soil being very fertile and the water supply sufficient. The trees grow to a height of 6 metres (1 metre equals about 39½ inches) and produce more vigorous specimens than those in Salvador. In Nicaragua the prospects are variable, but are usually considered satisfactory in rainy districts. In dry districts irrigation of cacao estates is carried out at great expense and in a systematic manner; according to Preuss† each row of cacao is, on some estates, supplied with a separate irrigation channel. In Salvador, cacao cultivation is not as good as in Nicaragua, though good varieties appear to be grown there. The dry climate of parts of Nicaragua affects the vegetation considerably, and the methods of cultivation, especially in reference to shade trees and irrigation, are peculiar in districts where the annual rainfall is sometimes only 1,800 mm. (1,000 mm. equal 1 metre.)

British Honduras.—According to a recent Colonial Report several cacao plantations are now established in British Honduras, and some are producing fair crops. The report states that whereas a few years ago cacao was imported from London to supply local requirements, during 1904 British Honduras produced sufficient to satisfy home demands, and exported a quantity of the produce to Europe.

Cacao in South America.

Venezuela.—Though many products are cultivated in Venezuela, cacao occupies the most important place, and the high quality exported under the name of "Caracas cacao" has long been known. There are, however, no cacao plantations of exceptional importance in the neighbourhood of Caracas, most of them being, according to Preuss, near the coasts in Carabobo, Guzman, Blanco, and Lara. Many of the estates are provided with artificial water supplies owing to the insufficient rainfall. The

* W. Fawcett, Jamaica Bulletin, September, 1905.

† Expedition nach Central-und Südamerika, by Dr. Paul Preuss. Kolonial-Wirtschaftlichen Komitees. Berlin, 1901.

climate is favourable for cacao cultivation; the better varieties of cacao begin to yield fruits in their sixth or seventh year, and the inferior kinds in the fourth year; an average yield of one pound of cured cacao per tree, per year, is generally expected.

Ecuador.—The tables given in the chapter dealing with the exports of cacao indicate that Ecuador is among the most important cacao-producing countries in the world, and is in this respect remarkable. Cacao trees are said to grow wild or to be indigenous in this part of the South American Republic; the moist hot climate, good soil, and transport are favourable to its cultivation. The cultivation of cacao in Ecuador is not in a very advanced state, and much better values and yields might be obtained by more careful attention to curing, fermenting, manuring, and pruning. The cacaos exported from Ecuador are relatively uniform in quality, and are known more according to their place of origin than botanical characteristics.

Surinam.—This country has for several years exported a few thousand tons of cacao annually, and much information regarding the methods of cultivation in that area has been made known through the investigations of Preuss. As a cacao-exporting country it is as important as Ceylon and more important than Jamaica, Haytii, the Cameroons or the Dutch East Indies. Much of the land, in districts suitable for cacao, is liable to floods in the rainy weather; the draining of the soil, especially in areas close to salt water, is often expensive and difficult; the accounts given by Preuss forcibly remind one of the nature of similar operations in the alluvial coastal lands in the Federated Malay States and the Straits. The rainfall is only about 2,500 mm. per year.

The varieties cultivated in Surinam are considered to be somewhat inferior; they are known as the Surinam, Alligator, and Caracas forms, though, as will be shown elsewhere, these names have but little significance and the cacao seeds obtained therefrom are mainly flat, small, and purple. The cultivation of cacao is not very advanced, though the fermenting processes appear to be well understood and practised.

Export of Surinam Cacao:—The cacao from Surinam is nearly all sent to North America, though small quantities are shipped to Holland. The following was the export of cacao for the years 1890 to 1898, and, according to Preuss, there is a prospect of the industry continuing to flourish.

Year.		Kilograms.	Year.		Kilograms.
1890	...	2,181,347	1895	...	4,456,338
1891	...	2,210,695	1896	...	3,302,567
1892	...	1,665,700	1897	...	3,424,513
1893	...	3,435,890	1898	...	2,833,993
1894	...	3,335,179			

British Guiana.—The cacao from British Guiana obtains a good price, and in quality is reported to come second only to that

of Trinidad, but the exports do not indicate that much interest is being taken in this particular cultivation.

Cacao in the East Indies.

Ceylon.

General History.—It is difficult to trace the exact date of the introduction of cacao into Ceylon; its origin is somewhat obscure in this island, but there appears to be no doubt that it was grown in the Botanic Garden, Kalutara, in 1819. It may have been introduced by Moon, but the main part of the cacao cultivated at the present time is probably the offspring of the plants obtained from Trinidad by Sir R. Horton in 1834-5 and the varieties imported in 1880 and 1881 from the same place. Ondaatje, in his report as Acting Suprintendent of the Botanic Gardens, in 1843, states that a large number of seeds was distributed throughout the island. The more serious questions of selection of varieties, distribution, cultivation, and pests were dealt with by Thwaites, Trimen, and Willis; the industry is at the present time left mainly in the hands of the planters of Ceylon and the staff at Peradeniya.

From 1866 to 1876 the energy of the Botanic Department was directed to the distribution of seeds and to the circulating of instructions regarding the cultivation of cacao; during that period Messrs. Worms, Bayley, and Corbet introduced more seeds of the Caracas type. Many efforts were, and have since been, made to induce the villager to take up the cultivation, but with very little success. In 1874 no less than 40,000 seeds were distributed among Ceylon residents; these were either planted in village gardens under the shade of Jak trees (Artocarpus integrifolia), or on estates to supplant coffee wherever the latter had suffered badly from the leaf disease; the demand for seeds grew at an encouraging rate, and planters in India became interested in the new Ceylon industry.

During the next ten years the export of cacao gradually rose, good prices were obtained and new varieties introduced. Seeds were distributed to all parts of the island and the Dumbara, Kurunegala, and even Negombo districts took an active interest in the cultivation, many planters then pronouncing cacao as a favourite product.

New Varieties: Appearance of Helopeltis.

In 1880 and 1881 perhaps what were the most important events in the Ceylon cacao industry occurred; the Botanic Department obtained, through Mr. Prestoe of Trinidad, a good supply of new kinds, eleven varieties being selected and packed in Wardian cases by him and despatched to Kew; these were subsequently brought by Clark to Ceylon on the 5th November, 1880. This consignment contained plants of the Cundeamor, Forastero, Criollo, Cayenne, Verdilico, and Sangre Toro varieties of cacao, from which a selection was afterwards made for

distribution. The eagerness of the planters was, however, somewhat damped by the discovery of a disease which attacked the fruits and slender shoots in 1883, and in the two following years the check to the cultivation was obvious; it was, to the satisfaction of all, soon shown that the punctures on the fruits and leaves were due to Helopeltis which was then only very serious in places too lightly shaded or much exposed, and with this reassurance the industry again revived.

In the year 1890 the prices obtained for Ceylon cacao attracted the attention of planters throughout the tropics. Some samples fetched 106 and 107 shillings per cwt. in London, and from Trinidad—the home of most of our cacao—came inquiries for information regarding the methods of cultivation, fermenting, and curing. Though cacao was giving excellent results it was obvious at an early date that the range of climate under which it could be profitably grown was relatively small, and that the villager could not be induced to take an interest in the product. In 1892 there was a shortage of crop attributed to drought, while in the same year complications set in owing to large quantities of cacao being regularly stolen by villagers in the Matale district, a habit which ultimately led to the introduction of an Ordinance to deal with such cases.

Exchange of Seeds.

The distribution of cacao had not been confined to Ceylon residents; plants were sent to Singapore and Fiji in 1880, a consignment was despatched to Queensland in 1886, to Bombay and Zanzibar in 1887, and to British Central Africa in 1893.

In 1893 a consignment of plants was sent to Trinidad; this consisted of a Wardian case of 56 plants of Ceylon "Old Red"; in this way was completed an interchange between the original and adopted home of cacao, one which has recently been repeated with plants of Hevea brasiliensis between Ceylon and Brazil. In 1895 Ceylon received, from Hart of Trinidad, a consignment of Nicaraguan plants named Theobroma cacao, var. pentagona, Theobroma cacao, var. angustifolia, and Theobroma cacao, var. Criollo, the last one probably being that which is only now coming into prominence on account of the high qualities of the seeds obtainable therefrom.

Revival of Diseases in Ceylon.

There then came into prominence a disease, or what may yet prove to be a series of fungal diseases, which attacked the fruits and stems, and on neglected estates almost rendered the cultivation unremunerative. The disease was noticed especially just prior to 1896, and happily for the industry, botanists were appointed by Government to investigate the nature of the diseases and to frame remedial measures which have since proved effective, and have been responsible for the maintenance of the cacao industry.

Recent Developments in Ceylon.

It is a matter of common knowledge that the value of Ceylon cacao has, during the last few years, fallen considerably, and had it

not been found that this product could be profitably cultivated as a permanent intercrop with Para and Castilloa rubber, the industry would in all probability have remained stationary. While the value of Ceylon cacao has recently shown a marked decline, that of many other countries has not done so; numerous local applications have been received, asking for information regarding the varieties to be selected, the suitability of each in conjunction with rubber, and other matters. In the Matale, Kurunegala, Dumbara, and other districts the combined cultivation—cacao and rubber—is rapidly extending, and seems likely to prove a very remunerative one.

The output and value of cacao from Ceylon are obvious from a consideration of the following, supplied by the Principal Collector of Customs, Colombo:—

Statement showing the quantity and value of Cacao exported from the Island of Ceylon during the years 1875 to 1905:—

	Cwt.	qr.	lb.	Rs.	Rs.	cts.
1875 ...	No heading in Returns.				Value per cwt.	
1876 ...		do				
1877 ...		do				
1878 ...	10	0	0	100	10	00
1879 ...	42	0	0	2,290	54	52
1880 ...	121	1	24	3,500	28	92
1881 ...	282	3	3	15,405	54	62
1882 ...	864	0	15	46,488	53	80
1883 ...	3,376	3	20	151,961	45	01
1884 ...	9,241	1	26	323,451	35	00
1885 ...	7,466	1	22	298,657	40	00
1886 ...	13,056	0	24	548,361	42	00
1887 ...	17,460	1	12	838,097	48	00
1888 ...	12,231	0	6	580,975	47	50
1889 ...	18,849	0	18	999,005	53	00
1890 ...	15,942	2	1	797,125	50	00
1891 ...	20,015	2	19	1,200,940	60	00
1892 ...	19,176	3	2	1,342,373	70	00
1893 ...	29,775	3	3	2,121,524	71	25
1894 ...	22,791	3	11	1,139,592	50	00
1895 ...	27,522	3	20	1,128,440	41	00
1896 ...	33,890	3	5	1,101,450	32	50
1897 ...	35,121	0	24	1,299,484	37	00
1898 ...	38,098	3	21	1,676,353	44	00
1899 ...	42,527	2	26	1,875,047	44	00
1900 ...	33,696	3	12	1,651,146	49	00
1901 ...	47,471	0	0	2,321,331	48	89
1902 ...	61,476	0	0	2,537,764	41	27
1903 ...	59,098	0	0	2,248,145	38	04
1904 ...	67,355	0	0	2,448,354	36	34
1905 ,,	69,431	0	0	2,433,556	35	04

Changes in Methods of Cultivation and Preparation.

The price of R70 per cwt. obtained in 1892, as against that of R35 per cwt. in 1905, takes us back to the most vital consideration, *i.e.*, the variety or quality of the cacao grown and exported during these periods. Since the ravages of the disease or diseases affecting the stems and pods first became prominent in Ceylon, there has been a tendency to replace the old Criollo or Caracas variety with the more prolific varieties of Forastero and Amelonado, in the belief that the latter were not as liable to the ravages of parasitic fungi. Now, however, the planters are beginning to realise that all varieties of cacao at present cultivated in Ceylon are liable to be affected by the same diseases, and when the latter appear in the fluted and high stems of the Forastero variety are very difficult to effectively eradicate. There has been, during the last two or three years, a distinct tendency to plant the old Caracas type in preference to the Forastero; the change of variety can be shown to be one of the factors responsible for the varying value placed upon the cacao exported from Ceylon.

During recent years the cultivation of shade trees for cacao has also undergone considerable change, for whereas the original plantations contained mixed species of forest types, or a preponderance of *Erythrina umbrosa*, they are now giving way to *Hevea brasiliensis*, *Erythrina lithosperma*, *Castilloa elastica* etc.; furthermore, the results of experiments indicate that the shade of *Erythrina lithosperma* need not be permanent throughout the whole year, but may be treated so as to form a shade of varying intensity according to the seasons. In most of the species mentioned above there is observable one important and common agreement, *i.e.*, they change their foliage annually and thereby return large quantities of organic matter, in the form of leaves, to the soil. Methods of manuring have also changed, to some extent, during recent years; general change in modes of cultivation can be shown to affect the quantity or quality of the cacao produced. The Ceylon methods of cultivation, particularly with regard to pruning, weeding, and manuring are almost unique, and the differences observable in Surinam, Trinidad, Grenada, Samoa, Cameroon, etc., provide interesting material for consideration.

In Ceylon the methods of fermenting, washing, and curing are often quite different and sometimes quite contrary to those of other countries, though the effect of these processes on the quality of the cacao is only too fully recognised. In the opinion of many, the condition of the trees, whether they are free or suffering from disease, is of importance in determining the quality and quantity of the cacao.

It is therefore obvious that there are several factors which should be considered in connection with the present and past condition of the cacao industry in Ceylon; these will be dealt with in the respective sections.

Cacao in the Dutch East Indies.

Java.—In the Dutch East Indies cacao cannot be said to have attained to an independent cultivation, most of the trees occurring partly in compounds as garden plants and partly on plantations in conjunction with other products.

Dr. Zehnter, for some time Director of the Experiment Station in Salatiya, calculated the* area under cacao in Java at about 10,000 bouw or 7,000 ha. He supposed that an average of 500 trees occupy a bouw, so that the number of cacao trees existing in Java was about 5,000,000, and of these, allowing for disease and injury, about 3,000,000 yielded profit. Zehnter attributes the small yield obtained in Java partly to the fact that the cacao is often cultivated on land which has previously been under coffee, and partly to poor methods of cultivation and to diseases mentioned elsewhere.

The export of cacao* from Java during the years 1890-1903 was as follows:—

1903	1,376,243 kg.	1898	963,800 kg.
1902	827,761 ,,	1897	849,945 ,,
1901	1,200,088 ,,	1895	920,431 ,,
1900	1,266,066 ,,	1893	508,092 ,,
1899	1,060,354 ,,	1890	375,749 ,,

Cacao is also cultivated in the Celebes and the Moluccas, and the total export for the Dutch East Indies is given below:—

1902	889,938 ,,	1897	882,545 ,,
1901	1,276,689 ,,	1895	960,291 ,,
1900	1,342,248 ,,	1893	546,104 ,,
1899	1,089,712 ,,	1891	408,533 ,,
1898	974,773 ,,	—	—

Cacao in Samoa.

The Caracas and Forastero varieties of cacao were first experimentally grown in Samoa by German authorities on their plantations near Apia. In 1892 a favourable report on the quality of the bean was received from Germany. In 1893-4 a large number of seeds were distributed among the Samoans, and a few small plantations were started by some of the more enterprising of the British and other foreign residents. The number of small plantations is rapidly increasing though the amount of land in 1899 bearing cacao trees was estimated to be only 75 acres.

According to one authority† the "introduction of cacao into Samoa dates from 1883, when 100 trees were procured from Ceylon; these were followed in 1884 by 383 young trees obtained from

* Die Kakaokultur und der Kakaohandel Niederlandisch-Indien. Der Tropenpflanzer, No. 8, August, 1904.

† Bulletin of Imperial Institute, London, Vol. II., No. 1. March 31st, 1904.

Java. The industry has not yet attained any great magnitude, but there are great expectations of its ultimate success, and much attention has been paid to it. In 1899 the area under cacao was estimated at 300 acres planted by foreign residents and an unknown area on native lands. The Customs Returns show 400*l* worth of cacao exported in 1901 and 625*l* worth in 1902."

In recent times the cacao cultivation in Samoa has received a check owing to the appearance of diseases of a virulent type, but measures have now been taken to prevent the introduction of seeds or plants from countries where diseases are known to prevail, and curative methods have been adopted by a large section of the planting community. Much of the success attending the cultivation of cacao in Samoa can be associated with the work of Wohltmann whose investigations are dealt with elsewhere.

Cacao in the Philippines.

Cacao is grown in many parts of the Philippines, and according to one authority * the plants were introduced there in 1670 by a pilot named Pedro Brabo, of Laguna Province, who gave them to a priest of the Camarines. Cacao is said to grow on unirrigated land on the peninsula of Zamboanga† where the annual rainfall is only 888 mm., but the most important cacao areas are portions of Mindanao and Negros where the mean annual temperature is slightly over 80° F., with a mean annual rainfall of from 1600 to 2200 mm. (61 to 88 inches).

The cacao has been planted mainly at low elevations up to one thousand feet altitude, and the plants produce seeds which are said to be of good quality. Fruits of the Criollo and Forastero variety have been observed by Lyon, and it is thought probable that the true Forastero may have been taken to the Philippines from Acapulco, Mexico.

Cacao in Africa.

According to one authority‡ cacao was being grown with satisfactory results in Africa during 1901. In 1902 the German Colony of the Cameroons estimated to ship 3,000 bags of cacao to be increased, probably to 10,000 bags, in 1906. McClounie, head of the Scientific Department of British Central Africa, reported in 1901 the successful shipments from Kew, and receipt at Lomba, of 210 plants which had been planted out and were doing well. Lagos is also reported to be taking an interest in cacao, and as having recently sent representatives to the West Indies to see how estates are managed in Trinidad and Grenada.

Cacao plants were obtained for British Central Africa through Kew Gardens, England, and distributed at a nominal sum to

* Historia de Filipinas, by P. Fr. Gaspar de S. Augustin.

† Cacao culture in the Philippines, by W. S. Lyon, Bull. No. 2, Manila, 1905.

‡ Tropical Agriculturist, Colombo, March, 1902.

planters who cared to give the cultivation a trial, though the report of McClounie* for 1901 does not give details as to the results of previous attempts if such were made. Seeds of selected varieties were sent to British Central Africa in 1893 from Peradeniya.

The little Portuguese island of St Thomé has greatly increased its export of cacao in ten years, the shipment in 1891 being under 4,000 tons, whilst in 1901 about 16,000 tons of cacao were exported

In the Transvaal cacao is not grown at the present time, but in a letter received from the Department of Agriculture it is stated that it is intended to try it experimentally at the Tzaneen Government Estate, situated some few miles south of the Tropic of Capricorn. Though coffee and tobacco thrive, it is doubted whether cacao will do so on account of the dryness of the winter season and relatively low rainfall. The cacao plant does not grow out of doors in Natal, and cacao cultivation in this area appears to be quite impossible.

Cameroon.—Cacao has long been known in Cameroon, and many recent developments in the cacao industry of this place can be traced to the activity of Preuss. In 1884 the industry was in a backward state owing to the absence of definite information regarding the best methods of cultivation; subsequently, Preuss, in order to improve the prospects of cacao in Cameroon, made a prolonged study of the subject in Surinam, Trinidad, Grenada, Venezuela, Ecuador, Nicaragua, Salvador, Guatemala, and Mexico; he obtained much useful information regarding the varieties of cacao, methods of cultivation, fermenting and curing, etc., in tropical districts where the cultivation was profitable.

The varieties originally planted in Cameroon were of an inferior kind, the Amelonado being the principal one cultivated; subsequently better varieties were introduced through the Botanic Gardens at Victoria, Cameroon, and Trinidad, the Forastero and other varieties thus obtained being superior to the original Amelonado.

West Africa.—The oldest trees in the Botanic Gardens at Aburi are now 18 to 19 years old, but in recent years a large area has been planted. This plantation is the origin of the cacao industry of the Gold Coast, and fruits have been regularly distributed by Johnson to the natives. The trees were first planted twelve feet apart and species of Erythrina first used as shade trees. The distribution still continues, and together with the establishment of local experimental gardens at Tarkwa and elsewhere, will effect an extension and improvement in the cacao industry of the Gold Coast. The progressive career of this part of the West Coast of Africa, in connection with cacao, is one worthy of emulation, and reference should be made to the tables, given elsewhere, showing how this area has gradually attained its present importance.

* J. McClounie, B.C.A. Gazette, October 31st, 1901.

Zanzibar.—The authorities in Zanzibar do not appear to have met with sucess in connection with cacao, as they report that "cacao is a most disheartening product to grow; it is the most delicate of all the economics.....nearly every insect attacks it." This was in 1900 and records of success have not yet been seen. In July, 1906, the Director of Agriculture, Zanzibar, informed me that the trials made with cacao some years ago were not sufficiently encouraging to justify an extension of the cultivation.

Queensland.—In the Kamerunga garden one of the old cacao trees was reported * to produce a few fruits in 1900, and the seeds not being required by planters were carefully sown and young plants reared. A consignment of selected varieties was sent to Queensland in 1886 from Peradeniya. The President of the Queensland Acclimatisation Society,—Leslie G. Corrie, Esq,—has assured me that while the cacao growth in the coast districts of the tropical north has been successfully proved, the product has not yet been taken up on commercial lines,

Cacao in India.

Many attempts appear to have been made to grow cacao in parts of Madras, Andamans, Bombay, Mysore, Bengal, Burma, and Assam; for the information on the results obtained I am indebted to F. G. Sly, Esq., officiating Inspector-General of Agriculture in India. Cacao does not appear to thrive in Bengal; it has been tried in Sylhet, Assam, and elsewhere and has generally been pronounced a failure. In Bombay the cultivation is not known, though one report states that cacao plants thrived there; in Mysore a few trees are known, one of which has produced fruits, but the product has not gained a footing there; in Burma a few trees are reported to be in existence, but are apparently gradually dying back.

In Madras several encouraging results have been obtained, plots have been extended and seeds distributed to intending cultivators; about 12 trees have been grown in Mangalore; in Trichinopoly some 35 to 40 trees are described as doing well and flowering in their third year when planted among low trees and bushes; and at Burliyar, at an altitude of 2,450 feet, satisfactory results are reported. The results obtained seem to indicate that cacao will thrive in the plains of Southern India only in such places as are well protected from wind and well supplied with moisture.

Cacao has been grown for many years in the Andamans, but the 6,120 plants reported in 1897-98 were reduced to 2,383 in 1903-04, large numbers dying each year, after reaching the bearing stage. It has been recommended for the brick red soil confined to the serpentine formations of the Saddle Range.

Though much more might be said regarding cacao in other countries, sufficient has now been written to show that this product is distributed throughout many islands and territories in the tropics, and is of considerable importance in commerce. It now becomes necessary to briefly describe the nature of the climates in some of the more prominent cacao-producing countries.

* Tropical Agriculturist, Colombo, 1900-01.

CHAPTER II.

CLIMATIC CONDITIONS IN CACAO-GROWING COUNTRIES.

CACAO is essentially a tropical cultivation, and is known in countries situated north and south of the equator. On the north side of the equator we have as cacao-producing countries, Ceylon, the Philippines, Cameroon, Gold Coast, etc., ranging from about 5 to 10 degrees latitude, and Mexico, Nicaragua, Surinam, Guiana, Salvador, Guatemala, Venezuela, Caracas and the West Indian islands from approximately 5 to 20° N. In the southern hemisphere the main cacao-growing countries are Java, and parts of Africa from 7 to 10° south, and Ecuador and parts of tropical Brazil from 5 to 20° S. Not only is the cultivation of cacao limited to places a few degrees on either side of the equator, but it is usually only considered to be a success in such areas where the altitude is very insignificant; an elevation from 200 to 800 metres includes the greater part of the cacao plantations in this equatorial belt. In this way it appears to present wide differences when compared with tea, cinchona, camphor and other tropical products, and to show similarities to cultivated plants such as the coconut palm, Hevea brasiliensis and others.

It is obvious, however, that in the countries enumerated above, the climatic conditions must present great differences, and it is therefore necessary to describe the prevailing conditions of temperature and humidity in a few of the typical areas where cacao is, or can be, grown.

Climate in Ceylon.

The combination of rainfall, temperature, and elevation required for the profitable cultivation of cacao eliminates many parts of the island for this product. The large tracts of land in the hilly districts cannot be included in the cacao zone on account of low temperatures or unfavourable moisture conditions. An elevation of 500 to 2,000 feet is considered to include the range for successful cacao cultivation, and a rainfall of 50 inches is near the minimum for this product. Cacao has been tried in districts having 200 inches of rain per year, but without success, and is also being tried in dry irrigable areas, but reliable results cannot be obtained therefrom for many years.

The following are the meteorological details of particular districts in Ceylon where cacao is, or might be, successfully grown (Surveyor-General's Report, 1902, and by letter) :—

District.	Annual Rainfall Inches.	Average Annual Temperature.	Average mean annual humidity.	Elevation Feet.
Henaratgoda ...	106·12	—	—	33
Kelani ...	161·06	—	—	250
Kurunegala ...	84·71	—	—	409
Kegalla ...	122·33	—	—	729
Kandy ...	81·52	75·5	78	1,654
Badulla ...	75·28	73·4	79	2,225
Passara ...	88·91	—	—	2,800
Matale ...	84·38	—	—	1,208

The Climate at Kandy.

In the Kandy district the south-west rains are heavy during April and June, and those of the north-east still heavier in October and November. To be brief there is a warm dry period during February and March, a hotter but moister one during April and May, followed by seven to eight months of rainy weather when the temperature is comparatively low and humidity high. We can therefore speak of one hot dry and hot moist season of four months and a cooler moist period for the rest of the year. The average mean annual temperature is about 75·5 F., the annual rainfall 82 inches and the average mean annual humidity about 78.

The following table shows the general distribution of rain, temperature, and humidity throughout the year in a district which is the centre of the Matale, Dumbara, and other important cacao-growing parts of Ceylon :—

Month.	Rainfall in Inches.	Mean Monthly Humidity.	Mean Monthly Temperature, Fahrenheit.
January	4·75	77	73·2
February	2·37	71	75·0
March	3·48	71	77·3
April	7·59	77	77·5
May	5·95	78	78·6
June	9·11	81	75·5
July	6·85	81	74·9
August	5·74	81	74·9
September	5·69	80	74·9
October	10·99	82	75·2
November	10·69	79	75·3
December	8·95	81	73·4

Most of the cacao-growing districts in Ceylon are affected by both monsoons. In the Uva province, however, the cacao districts receive their heaviest rain in October, November, and December, and during May to July the rainfall is at the minimum. In the Badulla district the annual rainfall is about 76 inches, the average mean annual air temperature about 73° F. and the mean annual humidity about 79.

Climate in the West Indies.

Trinidad,

The island of Trinidad is, according to Olivieri,* "south of the hurricane and cyclone latitude. The year comprises two seasons, the dry and the wet or rainy season. The dry season commences with the month of January, and ends in May; while the rainy season extends from June to the middle of December. The driest months are February, March, and April, and the wettest days are generally experienced during the months of July and August, with an interruption of very fine days from September to the end of October, known as the Michaelmas summer. The change from the dry to the wet season is generally characterised by a calm and close atmosphere with occasional showers of rain from the middle of May to the middle of June, while during the rainy season rain falls in torrents for hours without relaxation, often accompanied by flashes of lightning and peals of deafening thunder."

The temperature of the air in Trinidad is relatively equable, the range being between 69° F. and 89° F. The mean temperature for various years is given in the following table, and it will be obvious that it is a few degrees higher than the average for the Kandy district, but nearly the same as those for the districts near sea-level, in Ceylon.

Meteorological Details, Royal Botanic Gardens, Trinidad.†

	Inches of Rainfall.	Mean Annual relative Humidity.	Temperature mean maximum.	Temperature mean minimum.	Temperature mean Annual.
Record for 1887	64·09	79·	85·90	69·00	77·40
,, 1888	65·44	80	87·50	69·70	78·60
,, 1889	73·79	77·	87·57	70·10	78·90
,, 1890	82·90	79·	86·10	69·00	77·50
,, 1891	53·74	76·	87·80	70·10	78·90
,, 1892	91·14	80·	87·02	70·02	78·70
,, 1893	92·49	80·	87·44	68·58	78·01
,, 1894	52·21	78·	87·80	69·10	78·45
,, 1895	62·23	76·	87·80	69·50	78·60
,, 1896	66·45	80·	87·84	70·31	79·07
,, 1897	77·68	80·	87·91	70·35	79·13
,, 1898	57·63	80·	87·60	69·20	78·40
,, 1899	46·76	75·	89·30	69·50	79·40
13 years average	68·19	78·	87·51	69·57	78·54

The rainfall at the Botanic Gardens, Trinidad, appears to be lower than that at Peradeniya, though the average mean annual humidity is in each case about 78. The mean for 18 years was 66·48 inches, and the mean at 49 stations in Trinidad for 1905, 68·10 inches.

* A Treatise on Cacao, by F. Emmanuel Olivieri, Trinidad, 1902.

† (*a*) Cacao, by J. Hinchley Hart, Trinidad, 1900, and (*b*) L'Agriculture Pratique des Pays Chauds, November-December, 1903: Etudes et Mémoires, La Trinidad, by Gratien Candace.

Grenada.

I am indebted to the Officer in charge of the Botanic Gardens at Grenada for the following information regarding the distribution of rain in some of the cacao-growing districts of Grenada:—

Rainfall for 1903.

Month.	St. George's, Annandale.	St. David's, Les Avocats.	St. Andrew's, Dunfermline.	St. Patrick's, Springbank.	St. John's.	
					Dougaldston.	Belvidere.
	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
Jan. ...	13·75	10·49	6·82	6·69	8·43	15·02
Feb. ...	4·89	4·00	1·37	2·00	3·54	4·59
March.	5·80	4·91	1·03	1·32	1·76	5·54
April...	3·54	3·02	·99	1·34	2·33	3·42
May ...	4·97	2·78	3·17	5·27	4·11	6·91
June ...	14·22	12·40	6·88	8·68	10·91	13·17
July ...	16·77	14·87	11·92	10·13	15·90	22·38
August	23·77	19·10	17·83	21·52	18·82	27·98
Sept....	14·38	11·00	8·11	11·42	11·07	20·04
Oct. ...	15·72	14·18	7·93	11·19	9·26	19·10
Nov. ...	8·49	5·67	6·02	5·02	4·93	9·08
Dec. ...	22·90	23·77	10·06	11·52	16·06	20·97
Total...	150·20	126·19	82·13	96·10	107·12	168·20
1902 ...	136·27	100·57	70·89	66·10	102·34	151·29

Rainfall at St. Lucia.

The following details of the monthly rainfall in cacao-growing districts have been taken from the annual reports, issued by the Botanic Officer at St. Lucia:—

Month.	Rainfall for the month (in inches)			
	1902.	1903.	1904.	1905.
January ...	2·58	4·04	8·54	2·99
February ...	1·46	4·25	4·83	1·71
March ...	2·45	3·35	3·55	5·36
April ...	1·91	3·30	2·09	3·00
May ...	9·21	2·32	6·35	5·20
June ...	12·55	4·34	6·59	5·19
July ...	9·35	13·25	8·32	9·04
August ...	12·36	10·87	9·19	10·01
September ...	9·62	6·13	8·35	8·34
October ...	7·87	12·38	9·83	8·08
November ...	12·71	6·20	6·10	9·75
December ...	9·36	16·41	3·98	3·97
Total ...	91·34	86·84	77·72	72·64

Jamaica.

I am indebted to Mr. Buttenshaw for the following information regarding the rainfall in various parts of Jamaica:—

The Rainfall over the Island.

(From about 138 "average" Stations.)

1904.	N. E. Div.	N. Div.	W. C. Div.	S. Div.	The Island.
	Inches.	Inches.	Inches.	Inches.	Inches.
January	5·88	2·60	3·01	2·17	3.42
February	8·45	4·19	3·13	2·86	4·66
March	6·07	3·18	11·37	6·74	6·68
April	4·11	4·18	10·26	5·10	5·91
May	6·91	7·33	9·55	6·26	7·51
June	18·27	11·61	17·62	13·31	15·20
July	5·71	2·34	5·77	3·21	4·26
August	7·02	3·25	7·73	3·88	5·47
September	5·66	3·89	9·98	6·42	6·49
October	19·38	9·42	19·41	18·12	16·58
November	17·81	8·60	3·16	1·92	7·87
December	6·85	3·13	3·41	2·36	3·94
Totals	112·12	63·72	104·40	72·35	87·99

Climate in Tropical America.

Surinam.—Preuss states that the climate in Surinam can be divided into two dry and two wet seasons, the annual rainfall averaging between 2,200 to 2,300 mm. The first little dry season commences towards the end of February and continues till the end of May, the great rainy season then setting in and lasting until the end of August; the great dry season follows, and drought conditions prevail until the end of November, when the second little rainy season commences and continues until the end of February. The temperature is high, and though malaria prevails in the forests, the towns are said to be fairly healthy.

Venezuela.—Preuss states that cacao cultivation is hardly possible in some districts of Venezuela except on irrigable land, the rainfall often being less than 1,500 mm. in the year. The days are very hot, but the nights are comparatively cool.

Ecuador.—The climate in Ecuador is hot and moist, especially in the flat lands bordering the rivers. The cacao cultivation extends throughout the flat country in districts where the minimum temperature is never below 22°C. Guayaquil is described as having a hot rainy season from January to June.

Java.

The climate in Java varies, like that in Ceylon, according to the locality, but we have definite information regarding the climatic factors at Buitenzorg and East Java.

The climate at Buitenzorg differs from that at Peradeniya, Ceylon, in many ways. At Buitenzorg the rain during 1901 to 1904, inclusive, fell on an average of 263 days in each year. The humidity of the air in 1904 ranged from 75 in August to 85 in December, and the average for the years 1901 to 1904, inclusive, was 79. The average monthly temperature ranged in 1904 from 23·6 to 25·3°C. The climate at Buitenzorg is more equable than that at Peradeniya, but a definite periodicity does exist, the rainfall and humidity throughout the year approximating to those at Badulla in the Uva Province of Ceylon.

In East Java the climate is more exacting, and a comparison of the two places is given below.

I am indebted to Dr. Treub for the information in the following synopsis of the monthly rainfall, humidity, and temperature at Pasœrœan in East Java and Buitenzorg.

Climate during 1904 in Java.

	Rainfall in mm.		Monthly Average Mean Humidity.		Monthly Average. Mean Shade Temperature in °C.	
	Buitenzorg.	East. Java.	Buitenzorg.	East. Java.	Buitenzorg.	East Java.
January ...	417	221	83	77	24·0	27·2
February ...	455	192	85	80	23·6	26·9
March ...	169	287	80	80	24·5	26·6
April ...	204	33	79	76	25·0	27·4
May ...	541	155	80	76	25·3	27·3
June ...	389	27	78	73	25·1	27·1
July ...	312	48	79	71	24·8	26·7
August ...	344	18	75	67	25·1	27·1
September ...	388	—	76	64	25·3	27·7
October ...	799	11	81	64	24·9	28·7
November ...	312	24	80	67	25·2	28·7
December ...	498	110	85	74	24·2	27·9
Average mean yearly 1901—1904	4,416	1,200	79	71·9	25·0	27·6

Climate in Samoa.

The Samoan Islands possess a tropical and very equable climate. The usual range of temperature is from 68° to 88° F. According to one authority* "violent winds and thunder-storms are not of frequent occurrence. but severe hurricanes sometimes sweep over the islands, though only in every seven to nine years. The dampness of the air is not so great as would be expected in tropical islands, but it is high enough to meet the requirements of all moisture-loving tropical plants. In the rainy reason, which lasts from November to March, the air is usually almost saturated. In the dry season, lasting from April to the end of October, the hygrometer shows in the morning and evening about 90 per cent. and over of complete saturation, but at 2 P.M. about 65 to 75 per

* Bulletin, Imperial Institute, London, March, 1904.

cent. is observed; this circumstance is very favourable for the drying of cacao."

"As regards rainfall, the record kept at Apia extends from 1890 onwards. The mean annual rainfall for the 13 years, 1890 to 1902, is 115 inches, and the extremes in that period are a minimum of 89 inches and a maximum of 163 inches. As far as quantity is concerned, the minimum fall is sufficient for cacao and plants needing much water, but on the Samoan Coast the rain is not well distributed in the course of the year, and there are years when periods of drought last too long and are too intense to suit the needs of the cacao plant. If for two or three months in succession the fall is only 0. 8 in. per month the yield is very seriously threatened, and for this reason suitable localities at higher altitudes should be sought when selecting land for cacao planting as the rainfall is heavier in such situations". According to Wohltmann the climate in different parts of Samoa is very variable, the rainfall of selected places ranging from 1600 to 3500 mm. per year.

Africa.

The climate in the cacao-growing areas in Africa varies considerably, and though the differences between the meteorological conditions prevailing along the West Coast of Africa, Cameroons, St. Thomé. etc., are significant, the available data regarding the rainfall on the Gold Coast may be of interest.

In West Africa cacao is being grown in districts where the average mean temperature is about 80 to over 81° F. and the annual average rainfall only 50 to 60 inches.

The following table shows the rainfall and number of days on which rain fell during 1900-1904, at Aburi, Gold Coast :—

Month.	1900.		1901.		1902.		1903.		1904.	
	Rain-fall.	No. of Wet Days	Rain-fall.	No. of Wet Days.	Rain-fall.	No. of Wet Days.	Rain-fall.	No. of Wet Days.	Rain-fall.	No. of Wet Days.
January ...	1·51	3	2·11	5	·30	1	·73	1	1·	1
February ...	2·30	13	5·32	5	5·03	5	1·09	3	·55	2
March ...	2·72	4	4·53	8	3·82	9	5·89	6	4·16	8
April ...	4·88	8	4·07	6	7·01	10	2·63	9	1·84	5
May ...	3·14	6	5·48	9	3·27	10	4·56	8	6·24	9
June ...	5·72	15	6·87	10	7·09	11	7·44	11	6·47	13
July ...	2·48	18	6·89	14	2·07	6	3·72	13	2·19	7
August ...	1·49	15	2·57	14	2·93	7	1·58	10	·65	3
September..	2·29	14	6·97	24	·73	2	1·93	11	2·97	6
October ...	5·90	15	4·95	15	7·16	11	4·78	13	2·20	8
November...	2·53	4	5·43	10	2·16	2	6·60	14	·52	4
December...	2·69	5	1·23	6	·74	3	2·13	5	3·30	5
Total ...	37·65	120	56·42	126	42·31	77	43·08	104	32·09	71

(Annual Report for 1904 by Director, Botanic Department, Gold Coast.)

Climate in Queensland.

The information regarding the climate in the cacao-growing districts has been furnished by Mr. Leslie G. Corrie, who informs me that he has seen cacao successfully grown at Cairns and Kamerunga, and that other districts such as Cardwell and Port Douglas are situated similarly to these places. In view of the statement that cacao has been grown successfully in the coast districts, the following table of meteorological details is given:—

Month.	Cairns.			Kamerunga.		
	Rainfall. Inches.	Humidity.	Mean Temperature.	Rainfall. Inches.	Humidity.	Mean Temperature.
January ...	7·23	70	81·6° F.	9·96	79	81·5° F.
February ...	20·19	79	80·8° ,,	24·61	89	80·0° ,,
March ...	14·18	81	78·2° ,,	13·85	82	77·0° ,,
April ...	14·95	84	76·5° ,,	18·78	83	75·3° ,,
May ...	5·26	82	74·2° ,,	3·82	84	72·6° ,,
June ...	1·98	77	70·4° ,,	1·63	83	69·1° ,,
July ...	0·39	75	68·1° ,,	0·94	83	66·3° ,,
August ...	1·56	73	68·9° ,,	1·33	77	68·3° ,,
September..	0·79	64	72·2° ,,	0·62	71	72·0° ,,
October ...	3·13	67	75·7° ,,	2·47	73	75·1° ,,
November...	1·70	60	77·6° ,,	3·55	64	76·4° ,,
December...	6·53	68	81·4° ,,	3·01	74	81·3° ,,
Total ...	77·89			84·57		

Climate in India.

It has been previously shown that there are but few cacao-growing areas of importance in India at the present time; the details of the climatic factors at the various places mentioned have been obtained from F. G. Sly, Esq.

District.	Places where Cacao is grown.	Average Rainfall in inches per year.	Mean temperature.		Average humidity.	
South Canara	Mangalore ...	130.90	79.8°F		88	
Malabar ...	Calicut ...	118.69	80.6°F		82	
Nilgiris ...	Burliyar ...	80.00	82°F		—	
Trichinopoly.	Trichinopoly.	32.81	84.8°F		72	
			Max.	Min.	8A.M.	4P.M.
Andamans ...	Port Blair ...	114.70	87.4° F	77.0° F	85.5	76.6

The meteorological details given in this chapter will be of use as indicating the possible range of climate under which cacao can be or has been grown in tropical America, Africa, and the East and West Indies, and should be closely studied by those who propose to engage in the cacao industry in countries where irrigable land is not available. The nature of the cacao plant and its requirements can now be dealt with.

CHAPTER III.

THE BOTANICAL CHARACTERS OF CACAO PLANTS.

The Genus Theobroma.

THERE is no doubt that the greater part of the cacao of the world is derived from the species known as *Theobroma Cacao*, L. To the genus Theobroma belong other species which yield seeds somewhat similar to those obtained from *T. Cacao*, L.; though the characters of the plants and fruits from the trees of *T. pentagona*, Bern., and *T. angustifolia*, Moc. et Sessé., growing at Peradeniya, show many differences when compared with the same structures in *T. Cacao*. In the West Indies other species such as *T. bicolor*, Humb. et Bonpl., *T. sylvestris*, Mart., *T. ovalifolia* and others are also known, but do not appear to be largely cultivated.

Size of Vegetative Parts.

Trees of *Theobroma Cacao* grow at varying rates, but a height of 1.8 metres (about 6 feet) in three or four years, and 3.6 to 7.6 metres (12 to 25 feet) in ten to fifteen years may be expected; the branch system is profuse, and the spread of the foliar system increases from one having a diameter of about 1.5 metres (5 feet) when three years old to one of 6 to 7.6 metres (20 to 25 feet) in diameter at the end of the twentieth year. Some varieties, especially the Amelonado, have a tendency to produce a large proportion of bending branches near the base, and by this character and the smooth and pale green appearance of the leaves may often be recognised, even though fruits are not present. The root system consists of a stout and often very long taproot with a fibrous system of superficial rootlets; the surface system of rootlets is never very compact, and appears to be less extensive and weaker in some varieties than in others; in consequence of this a large proportion of the soil on mature cacao plantations is often free from the roots of the cacao tree.

The leaves vary in length from 25 to 34 cm. (about 10 to 13½ inches) and in width from 9 to 12 cm. (about 3½ to 5 inches). They are simple and acuminate in form, the surface is at first silky and reddish, but finally becomes slightly coriaceous and deep green; they attain their full dimensions on trees long before the latter flower, and are at first produced irregularly, but later appear more during certain seasons of the year. The tree is never leafless though there is often a heavy fall of leaf prior to the rainy season; the leaves are usually retained on old trees for periods exceeding twelve months.

The vegetative system is not what one would describe as a very vigorous type: trees which are exposed to strong winds are frequently uprooted, the leaves considerably torn and the young twigs dried and broken; the stems, leaves, and roots are subject to many parasitic fungi and insects. *Theobroma Cacao* is a product of the wild tropical forests of America where by means of adjacent trees it receives a certain amount of natural protection from wind, sun, etc., and even under cultivation to-day appears to require somewhat similar circumstances for its proper development.

Flowers.

Flowers may be produced when the plants are only three years old, and when the trees are mature they may occur in very large numbers each year; the largest number recorded for Ceylon from a single Forastero tree at one time is 27,632, whilst the average number produced per tree, per year, ranges over large acreages of mature trees from about 5,000 to 12,000. The flowers appear every month in the year, but are particularly abundant, at Peradeniya, during one season—May to June.

The flowers are hermaphrodite and occur on young and old twigs, either in the axil of a leaf or a leaf scar, or in places void of all traces of leaf attachments; they may be solitary or in groups, each flower being supported on a pale or reddish pedicel 15 to 20 mm. in length and 1 mm. in diameter.

The calyx segments form a pyramidical mass when in the bud state, but rapidly curve and hang downwards; the segments or sepals are five in number, straight, acuminate, usually yellow or red in colour, and measure from 4 to 8 mm. in length. According to Olivieri "a reddish calyx produces light red, or deep red fruits; but if whitish or grey, the fruits will be either light or greenish-yellow. When the calyx is vari-coloured the pods are either reddish or yellowish, and often both colours are seen". This relationship has not yet been confirmed in Ceylon, where a considerable variation has been recorded.

The corolla consists of much contorted petals, the flat terminal spathulate portions of which are generally yellow and the lower curved or hooded portions streaked red; the anthers of the inner fertile stamens are usually covered by the basal hoods of the petals. The pistil, provided with a short divided style, is rarely more than 3 mm. in length, and is subsequently transformed into the fruit. The fruits are many-seeded and vary from 16 to 21 cm. in length, and 22 to 29 cm. in circumference. The illustrations given elsewhere show the general characters of all parts of the tree and the occurrence of fruits on stems and branches.

Insects and Pollination of Cacao Flowers.

Dr. Uzel, on the occasion of his visit to Peradeniya, carried out a few experiments on the subject of pollination of cacao flowers.

The flowers of cacao trees grown under dense shade and in the open were examined, and in those flowers well supplied with sunlight large numbers of *Thrips* were found. Dr. Uzel was of the opinion that cacao flowers were pollinated solely by Thrips and that these insects occurred in the largest numbers where trees were exposed to sunlight or where flowers were thus exposed by pollarding of the branches of the cacao trees. Isolated cacao trees do bear large crops, but this may be due to the increased or unlimited food supply available to such specimens, as well as to the increase in the number of pollinating insects. Green has recorded the occurrence of thirty specimens of a common Aphis (*Ceylonia theæecola*, Buckt.) in a cacao flower, each being dusted with numerous pollen grains.

Varieties of Theobroma Cacao.

There are many varieties of this species under cultivation which either on account of their adaptability to cross-fertilise, or for other reasons, now form a more or less continuous series between the Criollo and Forastero types; other varieties known as the Amelonado and Calabacillo seem to form a more distinct group, though it is usually admitted that they have been derived from the single species under consideration. The varieties can be distinguished more by the colour, shape, surface, and size of their fruit walls, the colour and size of the seeds, than by differences in vegetative characters. It is difficult to trace the whole of the varieties to one common type, though the Criollo or Caracas is supposed by many to have occupied this importance at one time—a parentage difficult to associate with types like the Amelonado, the fruits of which always contain 100 per cent. of flat purple seeds, and in this constant characteristic stand apart from most of the Forastero forms linked to the supposed Criollo parent. The Amelonado type is surrounded, in Ceylon, with Forastero, Criollo and Nicaraguan forms, and though the latter, in their fruit walls and seeds, show every indication of having interbred and form a more or less continuous series, the Amelonado remains constant and does not show those striking differences in habit, fruit or seed characters, such as one would expect if its ancestors were affined to the Criollo type. This constancy of the Amelonado trees, repeated in successive generations, contrasts very strikingly with the multifarious variations of most other forms, and suggests a distinct group arising from ancestors not yet clearly defined. Apparently the Calabacillo forms, of which no good or true representatives are known in Ceylon, approach near to the Amelonado, the two types forming a group relatively distinct from all others in fruit and seed characteristics.

Other Species of Theobroma.

Theobroma pentagona.—This species, indigenous to Central America and distributed to Trinidad and Ceylon, produces a good cacao. The fruits, which are green or red in colour, are covered externally with irregular, rounded, warty structures resembling

Photo by Ivor Etherington.

TYPICAL FORASTERO TREE.

scales, and Preuss states that to this peculiarity the term Lagarto or Alligator is due; prominent ridges run lengthways and between these is the warty surface. The seeds are similar in size, etc., to those of the Nicaraguan cacao and are said to be used with those of *T. Cacao* in the manufacture of chocolate and cacao powder; they are white or purple in colour.

Theobroma bicolor.

This species is indigenous in, and is widely distributed throughout, Central America, and yields seeds which are usually consumed where cultivated. It occurs wild, according to Preuss, in Ecuador, where it is known as "Cacao blanco" and in Columbia where it is termed "Bacao"; in different parts of Central America it is often called "Pataste", "Pataschte" or "Patastle". This species, when it occurs wild in the forests of Ecuador, is described by Preuss as having a stem 12 metres in height, leaves with a bluish-green tinge on the under surface, and flowers of a red colour with deep purple anthers. The fruits are very woody, green when unripe and yellowish or brownish when ripe; one dried specimen, received at Peradeniya from the West Indies, was characterised by very prominent reticulated veins. The seeds are large, flattish, white or yellowish-white in colour, and not bitter to the taste; they are said to contain a large proportion of fat and to be consumed largely where grown. Hart states that he found this species indigenous in the province of Veragua, United States of Columbia, in 1885, and describes it as one producing a poor class of cacao and as being recognisable in the dry state by the prominent reticulations of the fruit wall. Forms described as *Theobroma angustifolia*, *T. guianensis*, and *T. sylvestris* also produce cacao of variable but generally inferior quality.

T. angustifolia occurs in the wild parts of Central America, and has been recorded from Nicaragua, Salvador, and Guatemala by Preuss. It is also said to occur in Mexico, though its seeds have no market value.

The species, which have been described by Prof. Schumann, Berlin, in his work on the Sterculiaceæ of Brazil, are very numerous, and reference should be made to his descriptions by those who desire to obtain a detailed knowledge of *T. speciosum*, Spreng, *T. microcarpum*, Mart., *T. grandiflorum*, K. Sch., *T. subincanum*, Mart., and other species of this interesting genus.

Herrania balaënsis, Preuss.

Herrania balaënsis, known as "Cacao del monte," was discovered by Preuss in the neighbourhood of Balao, and is described as possessing a simple, thin, straight stem some 6 metres in height and bearing a large crown of branches and foliage. The flowers are conspicuous, provided with long pedicels and occur in clusters of 12 to 15 individuals on the stem: the fruits, well shown in

the illustration given in Preuss's book, occur in bunches, are somewhat egg-shaped and covered on the surface with prominent ridges; they are olive-green in colour when young, yellowish-green when ripe and are characterised by a long and bent apex. The seeds are white and surrounded with a conspicuous pulp, which appears to be consumed in preference to the kernels.

Much more could be written on the various species which are described as yielding seeds resembling the true cacao of commerce, but as *Theobroma Cacao* is the principal species cultivated in the tropics, only a detailed account of the recognised varieties of this form need be given.

CHAPTER IV.

VARIETIES OF CACAO AND SEED SELECTION.

THE trees on an average cacao estate in Ceylon present great diversity, the greatest variation being in the sizes, shapes, and colours of their fruits; considerable variation is also found to occur in the characters of the seeds, and on first examination one might be excused for concluding that the variations were of a very connected or continuous nature. A close study of the fruit and seed characters shows, however, that the types are frequently well defined and in a few cases remarkably constant, though in the majority of instances a wide range of variability in fruit and seed characters is manifest. The varieties of cacao in Central and South America have been recently investigated by Preuss in a most thorough and scientific manner, and those in the West Indies by Morris, Hart, and others; the information now available allows one to make a comparison, of some value, with the types cultivated in Ceylon. The classifications at present adopted are either of a commercial or botanical nature, the former usually dealing only with seed characters of use to purchasers, and the latter of a more detailed nature to furnish cultivators and purchasers with some useful system of classification.

Commercial Classification of Cacaos.

Jumelle*, in his interesting chapter on the chemical and commercial studies of cacao, deals with the cacaos according to their (1) American, (2) African, (3) Asiatic and Oceanic origin, and gives some interesting observations regarding the general characters of cacao exported from each of these vast areas.

The American cacaos are the most important, and are divided into those of the continent from Venezuela, Ecuador, Brazil, Guatemala, and Columbia, and those from the islands of Cuba, Trinidad, Guadeloupe, Martinique, Saint-Lucia, Jamaica and Hayti, etc. Of the American continental cacaos the Venezuela is described as the most valued in Europe and comprises two main kinds, the better one coming from La Guayra, Port of Caracas or Puerto Cabello; the inferior kind is called Carupano and is often sent to Trinidad. The Trinidad cacaos were at one time highly appreciated, but today the good kinds grown in the colony are said to be scarce on the markets. The cacaos from Saint-Lucia and Jamaica are, according to Jumelle, inferior in quality. The characters of types of African and Asiatic cacao are given in the accompanying synopsis. The "Old Red" of Ceylon is still regarded with favour on most markets for its appearance and quality, and only quite recently a price of over 80 shillings per cwt. was paid for some sent from Ceylon.

* H. Jumelle, Le Cacaoyer; (chap. Étude chimique et commerciale des cacaos.)

The following table will indicate the colours, shapes, and sizes of many commercial cacaos as determined by Jumelle and others :—

COLOURS, SHAPES, AND SIZES OF COMMERCIAL CACAOS.

Kind of Cacao.	Shape.	Colour.		Size in Mm.		
		Integument.	Kernel.	Length.	Width.	Thickness.
Venezuela. 1st grade...	Elongated, rounded, laterally convex on large surfaces	Reddish & covered with claying materials ...	Currant-coloured..	25	15	8
Guayaquil. 1 ...	Unequally convex on large surfaces	Blackish-brown ...	Blackish-violet ...	18	12	8
2 ...	More flattened	Do. ...	Blackish-grey ...	22	15	7
3 ...	Convex surfaces	...	Dark-brown	—	—	—
Brazil. 1. Para-Maragnan. (The Columbia cacao resembles this)..	Elongated, rounded on one side, pointed on the other; slightly flattened ...	Red ...	Brown ...	Variable sizes.		
2. Bahia..	...	Red-veined	Brown ...	18	12	6
Surinam ...	...	Greyish-brown ...	Reddish-brown ...	24	12	6
Cayenne ...	Flat and unequally convex	Blackish-brown ...	Brown ...	22	12	4
Berbice ...	Large, uniform, short, and round ...	Red ...	Blackish-grey ...	—	—	—
Martinique. 1 ...	Flattened and concave ...	Deep-red...	Slate-coloured ...	—	—	—
2 ...	Flattened and elongated ...	Do. ...	Violet ...	—	—	—
Hayti ...	Small, elongated, a little flattened ...	Dark-brown or black...	Dark-brown	20	12	5
Africa. 1. San Thomé.	Flattened and unequally convex ...	Blackish-brown ...	Do. ...	—	—	—
2. Armor...	Small, flattened ...	Do. ...	Slaty-grey.	—	—	—
3. Ancel-Seitz ...	Elongated, larger than (2) & more convex	Do. ...	Slaty-brown	—	—	—
4. Caya ...	Flat and elongated ...	Clear-brown	Do. ...	25	13	7
5. Cape Lopez ...	Long, flat, and narrow ...	Brown ...	Brown ...	22	11	4
Ceylon. Peradeniya. 1 ...	Rounded and plump ...	Reddish-brown ...	Cinnamon colour ...	23	14	8
2 ...	Round and elongated ...	Do. ...	Dark-brown	25	13	8
3 ...	Flat, small ...	Do. ...	Blackish-violet ...	22	13	7

Photo by H. F. Macmillan.

FORMS OF CACAO FRUITS.

Nicaraguan Criollo (1, 2 and 3); Theobroma pentagona (4); Amelonado (5); Criollo or Caracas (6); Forastero (7, 8 and 9).

Botanical Characteristics of Varieties.

The general characters of the numerous varieties of cacao grown in Ceylon and other countries may now be outlined in order to see what features can be relied upon as indicating the value of the different forms of cacao. It has been shown, when dealing with the history of cacao in Ceylon, that most of our seed supplies have been obtained from Trinidad, and the systems of classification drawn up by Morris and Hart for the identification of the varieties in that island are, in most features, applicable to Ceylon. These classifications do not, however, apply to all the varieties at present recognised in Ceylon, Java, Central and South America, etc., and according to Preuss do not always strictly apply to the cacao in Trinidad itself; in several countries it has become customary to attach the name of the country to the variety of cacao grown or exported, hence we learn of the Trinitario, Java-Criollo,* Java-Porcelaine, Nicaraguan-Criollo, Surinam-cacao, Brussel-cacao, Moderboorn etc., and a classification or key to the varieties is required for separate countries. The following are the systems drawn up by Morris and Hart and the characters of the varieties in Ceylon as described by Lock †:—

Morris.	Hart.	Lock. Key to varieties in Ceylon. All the varieties here mentioned include both red and yellow sub-varieties as well as many other minor types :—
I.—Cacao Criollo ...	Class I. Criollo, or fine thin-skinned ...	Beans plump, majority white or pale in section; shell soft and relatively thin. I Criollo.
	1. Var. a. Amarillo ...	Beans very large, somewhat flattened. *a.* Nicaragua.
	2. „ b. Colorado ...	Beans half as large as 1, more rounded. *b.* Old Red.
II.—Cacao Forastero...	Class II. Forastero, or thick-skinned cacao ...	Majority of beans purple in colour; shell relatively hard and thick. II. Forastero.
(*a*) Cundeamor verrugosa amarillo (yellow)	Var. *a.* Cundeamor verrugosa amarillo ...	Pods acuminate and "bottle-necked," rough, beans of high quality, pale and rounded. *a* Cundeamor.
(*b*) Cundeamor verrugosa colorado (red)....	„ *b.* Cundeamor verrugosa colorado ...	
(*c*) Liso amarillo ...	„ *c.* Ordinary amarillo...	Pods various, usually not "bottle-necked," beans of fair to good quality. *b.* Liso.
(*d*) Liso colorado ...	„ *d.* „ colorado...	
(*e*) Amelonado amarillo	„ *e.* Amelonado amarillo	Pods ovate, nearly smooth, usually "bottle-necked"; beans of lower quality, usually flat and all purple. *c.* Amelonado.
(*f*) Amelonado colorado ...	„ *f.* „ colorado...	
	Class. III. Calabacillo, or small-podded, thick, smooth-skinned, flat-beaned ...	Pods ovate, smooth, small, not "bottle-necked"; beans small, flat, and all deep purple. *d.* Calabacillo.
(*g*) Calabacillo amarillo ...	Var. *a.* Amarillo ...	Not in Ceylon.
(*b*) Calabacillo colorado ...	„ *b.* Colorado ...	

* Mededeelingen omtrent de op Java aangeplante Cacaovarieteiten; L. Zehntner, Proefstation voor Cacao to Salatiga, 1905.

† Varieties of cacao in Ceylon, Circular, R.B.G., Peradeniya Vol. 2., No. 24, 1904.

Fruit Characters of Varieties in Ceylon.

Most of the varieties of cacao grown in Ceylon are roughly divisible into *(a)* the Old Red, Criollo or Caracas, *(b)* the Forastero or Hybrid, and the *(c)* Amelonado types. The classification given by Morris is simple, and that by Hart more detailed, though the latter does not, in my opinion, give a sufficiently minute sub-division to make it of everyday use on cacao estates in Ceylon. The ease with which new strains of cacao arise has resulted in confusion, and it is a very difficult task to formulate a key to include the distinctive characteristics of the varieties existing in any one country where cacao has been cultivated for twenty or thirty years. As far as fruit characters alone are concerned it would be no difficult matter to collect specimens which in point of size, shape, and colour form a more or less continuous series connecting the Nicaraguan, Criollo, and Forastero types with one another; even the same tree in a single year or in successive years may produce fruits differing widely in external characteristics, and when one considers the characters of the rest of the vegetative system and those of the seeds, the mixed nature of the varieties now cultivated is manifest.

The classification of the cacao varieties into three groups by Hart is, according to that gentleman, necessary, in order to distinguish between the Calabacillo and Forastero types. It is equally necessary to adopt a similar classification for the varieties in Ceylon and to perhaps omit the Calabacillo group (which is very rarely if ever met with in this island), and give the Amelonado variety a separate class, as it is so markedly different in its shape, green-yellow colour, and flat purple seeds from any other Forastero type.

In order to enable one to select the various types it will be necessary to deal very fully with the characters of the fruit wall and seeds.

Fruit Wall.

Thickness.—The thinnest walls are found in the Nicaraguan and Caracas, or Criollo types, and the thickest in the Forastero forms. The following figures show the thicknesses, lengths, circumferences, and weights of several fruit walls of cacao pods grown at Peradeniya:—

Variety.	Thickness of wall.	Length of wall.	Circumference in middle of fruit.	Average weight of 100 fresh fruit walls.	
				lb.	oz.
Nicaraguan ...	12 mm.	19·1 cm	28·0 cm	—	—
Caracas ...	13 ,,	17·2 ,,	23·7 ,,	48	4
Forastero ...	15 ,,	20·6 ,,	26·5 ,,	84	14
Amelonado ...	15 ,,	18·5 ,,	26·7 ,,	74	12

Photo by Ivor Etherington.

AMELONADO CACAO TREE.

It is obvious from these records that the most wasteful variety of cacao, as far as the thickness and weight of fruit wall are concerned, is the Forastero, and the most economical the Caracas or Nicaraguan types.

Colour.—The outer surface of the fruit wall is, in unripe specimens, red or green, these colours changing during ripening to reddish-yellow or yellow respectively. In the Forastero group the fruits show all proportions of red and green intermingled with one another, and even the Caracas fruits may be yellow or red. In Ceylon the Amelonado variety is distinct in always having a green wall changing to pale yellow on ripening. Usually, but not always, all the fruits on the same tree have approximately a similar colour or distribution of colours.

In Trinidad, as indicated by the classifications of Morris and Hart, each variety is subdivided into red and yellow forms, and the same applies generally to the varieties in other cacao-growing countries.

Colour of Outer Surface of Fruit Wall.

Variety.	When Unripe.	When Ripe
Caracas ...	Usually red ; frequently green	Usually reddish-yellow ; frequently yellow
Nicaraguan ...	Red or green	Reddish-yellow or yellow.
Forastero ...	Red and green ...	Reddish-yellow.
Amelonado ...	Green	Yellow.

Shape and size.—In shape and size there is every variation between the long pod with acuminate and frequently bent apex--as in some forms of Nicaraguan and Forastero--to the short, ovate, broad base and blunt apex of Amelonado. Some forms are constricted at the base--Forastero--Cundeamor and Liso--others are wide at the base--Sambito and Amelonado--and others intermediate between these.

Cacao Seeds and Their Characters.

In shape, size, and colour the seeds vary considerably. The shape is sometimes flat as in Amelonado, Calabacillo and some forms of Nicaraguan, round and plump in forms of Caracas and Nicaraguan, long and more or less rounded in Cundeamor and other Forastero types. The size varies according to the part of the fruit occupied by the seeds, those at the ends usually being smaller—and also more irregular or flatter—than those in the middle ; the largest size is seen in theNicaraguan and Caracas fruits, and the smallest in the Forastero types.

The colour of the seeds varies from white to deep-purple in the same fruit or in fruits from different varieties. Generally the seeds of the Nicaraguan and Caracas varieties are white, those of the

Forastero types white or purple, in varying intensity, and those of Amelonado and Calabacillo all deep-purple. There is, however, a great variation in the number of white seeds in the first-mentioned varieties, and more often than not the cacao trees on plantations in Ceylon possess fruits with white and purple seeds, or with all the seeds purple. It is very rare that all the seeds in the fruits from one tree are white, even with the Caracas and the more recently introduced Nicaraguan forms; much of the unevenness in the finished product is to be attributed to this unfortunate variation.

It has been shown by Lock* that out of nearly seven hundred fruits of the Caracas variety about 58 per cent. of them possessed white seeds only, 40 per cent. white and purple seeds, and 1·8 per cent. purple seeds only. In the particular set of fruits referred to, 84·7 per cent. of the seeds were white and 14·2 per cent. distinctly purple, thus showing that though the reputed original character still predominates, the mixed seeds are becoming very prominent. In most cacao-growing countries the Caracas or Criollo type is supposed to possess white seeds only. Similarly a large percentage of the seeds of the Nicaraguan, which are commonly supposed to be white, were found to be mixed, but the white remained predominant in some types of this group. The Forastero types always possess coloured seeds, and though as many as 18·8 per cent. of the fruits contained purple seeds only, none were seen with white seeds only; the seeds of 180 fruits of this group possessed 61·8 per cent. of purple seeds and 37·4 per cent. of white ones, thus proving the existence of a definite quantitative difference between the Forastero and the preceding Criollo types. The Amelonado and Calabacillo fruits possess 100 per cent. of purple seeds, white-seeded ones being unknown in Ceylon.

COLOUR OF SEEDS.

Variety of Cacao.	Fruits with white seeds only.	Fruits with purple seeds only.	Fruits with mixed seeds purple and white.	Percentage number of white seeds in fruits.	Percentage number of distinctly purple seeds in fruits.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Nicaraguan ...	48·2	18·8	33·0	64	36
Caracas ...	57·9	1·8	40·3	84·7	14·2
Forastero ...	00·0	18·4	81·6	37·4	61·8
Amelonado ...	00·0	100·0	00·0	00·0	100·0

According to Hart, the Criollo or Caracas variety in Trinidad possesses white or nearly colourless seeds, a feature frequently associated with the seeds of the same variety in Java, Ceylon and Central America, and also with the produce of *Theobroma pentagona*; reference to the percentage number of purple seeds is not made, though it may be assumed that on most estates cultivating many varieties they occur. Regarding Nicaragua, Hart states that though the Criollo is the predominant type and the seeds are usually white

* R. H. Lock, Circular, R. B. G.

in section, there appears to be a perceptible increase in the colour of the seeds, and this he associates with the proximity of the Criollo to the Forastero types. The Venezuelan* cacao is mainly white-seeded and produces a cured bean of good colour and high-class flavour, without any bitter taste.

The variation in thickness and weight of the seed integuments has been dealt with elsewhere, and it is only necessary to mention that the thinnest integuments are found around seeds from Nicaraguan and Caracas fruits, and the thickest in the Amelonado and Forastero types.

The Parts of a Cacao Bean and Seed Selection.

The fresh cacao seed consists of a watery white pulp on the outer surface of a tough integument, the latter enclosing two stout cotyledons which form the greater part of the embryo, and are usually known as the kernel. Roughly the kernel is only responsible for half the total weight of the fresh seed, the pulp of the latter often being considerable. The weight of the seeds varies with the variety and other factors, the large plump ones being much heavier than the others. The weight of the cured seeds of different varieties is not constant, but the following table shows the average weight of several thousand seeds of four varieties grown at the Experiment Station, Peradeniya :—

Table I.

Variety.	Weight in Grams.
Forastero-Cundeamor ...	1·01 to 1·26
Caracas ...	1·19 to 1·35
Amelonado ...	1·00 to 1·10
Nicaraguan	1·31 to 1.80

According to Semler† the following are the weights of 100 cacao beans from various countries :—

Table II.

Kind.	Weight in Grams.
Trinidad ordinary	98
,, fine	123·2
,, extra-fine	178·7
Grenada fine	131·0
Caracas	130·3
Dominique	110·0
Surinam fine	122·0
Bahia	118·0
Mexican	136·5
African	128·5

Semler concludes that the average weight of a cacao bean is about 1·2 grams; a comparison of the weight of the seeds from varieties grown in any country should always be made. Regarding

* Annual Report, Botanic Department, Trinidad, 1904.
† Le Cacaoyer, H. Jumelle, p. 40.

weight only, the Caracas and Nicaraguan varieties in Ceylon compare favourably, but the inferiority of the Amelonado and Forastero types is equally pronounced.

Proportion of Integuments and Kernels.

This is an important subject in connection with seed selection, and is well worthy of consideration. The integuments of beans of the Caracas or Nicaraguan varieties are usually, but not always, thinner than those of the Amelonado or Forastero types, and the proportionate weight of integument to kernel is usually lowest in the round plump samples. Actual weighings often show very contradictory results owing to the variable amount of pulp, absorbed moisture, and dirt attached to the outer surface of the integument.

The following table shows the average proportionate weight of the integuments and kernels of different varieties of 100 cured cacao beans at Peradeniya :—

Table III.

	Weight of kernels only.	Weight of integuments	Total weight.	Percentage weight of integuments
	Grams.	Grams.	Grams.	
Caracas	116·2	10·8	127	8·5
Forastero-Cundeamor	103·0	10·3	113·3	9·0
Amelonado	94·7	10·3	105	9·8

The integuments on badly-washed or dirty beans vary considerably in weight, and in many such samples the proportionate weight of the integuments around Caracas beans is higher than that of clean beans of the Amelonado type.

According to the researches of Girard, Heisch, and Zipperer, the ratio of the weight of integuments to that of the beans from different countries is as given in the following table; the figures by Heisch are for the final product and the others for the raw beans :—

Table IV.

	Girard.	Zipperer.	Heisch.
Trinidad	9·82	14·68	15·50
Caracas	15·85	15·00	13·80
Puerto-Cabello ...	13·21	12·28	—
Guayaquil	10·32	—	11·50
Surinam	—	14·60	15·50
Para	10·39	—	8·50
Bahia	—	—	9·60
Ariba	—	18·68	—
Hayti	8·93	—	—
Martinique ...	8·97	—	—
Cuba	—	—	12·00
Grenada	—	—	14·60

The Ceylon beans are usually well washed and the integuments, having the minimum pulp and dirt, weigh less than other kinds; the integuments of Ceylon beans constitute approximately from 8 to 10 % of the total weight of the cured bean.

It is obvious from the foregoing figures that in Ceylon there is a wide variation in the average weight of cured beans from fruits of different varieties, hence those with the minimum weight must either bear better cacao, be more suitable for cultivation, or give larger crops of fruit; otherwise they should be eliminated in the selection of seed parents. It has also been shown that the different varieties have constant characters in the thickness or weight of the skin, cuticle, or integument surrounding the seeds; those varieties having the greater proportion of integument are obviously inferior.

Number of Seeds in Fruits.

It is now necessary to determine the average number of seeds, per fruit, and the average number of fruits borne by the different varieties.

The number of seeds per fruit varies considerably, but the following table indicates possible averages :—

Table V.

Variety.	Number of fruits.	Range in number of seeds per fruit.	Average number of seeds per fruit.
Amelonado ...	100	16 to 52	40·87
Caracas ...	100	16 to 42	31·45
Nicaraguan ...	175	24 to 36	28
Cundeamor ...	100	21 to 50	36·26

If the figures on tables I., III., and V., be compared, it will be noticed that the Nicaraguan and Caracas types have the heaviest seeds and lightest integuments respectively, but produce a lower average number of seeds, per fruit, than the Amelonado or Forastero-Cundeamor types. The Amelonado fruits contain the maximum number of seeds, but the latter are very light in weight and have comparatively heavy integuments. These results prove, however, that in weight of cured cacao from 100 fruits, integuments and kernels together, the Amelonado often comes first.

Table VI.

Variety.	Average number of seeds per 100 fruits.	Average weight of one cured bean.	Average total weight of cured cacao from 100 fruits.
Nicaraguan ...	2800	1·55 grs.	4340·00 grs.
Caracas ...	3145	1·27 ,,	3994·15 ,,
Cundeamor ...	3626	1·13 ,,	4097·38 ,,
Amelonado ...	4087	1·05 ,,	4291·35 ,,

To complete the comparison it would be necessary to give figures illustrative of the average number of fruits annually produced on trees of the four varieties, of known age, and when cultivated under identical conditions. Unfortunately no such figures, of a reliable nature, are at present available, and we are compelled to consider only general observations on this subject. Observed trees of the Nicaraguan variety, planted in 1895, gave averages of 25, 50, and 70 fruits each in the years 1903 and 1904; Cundeamor trees have annually given from 50 to nearly 200 fruits during the same period; Amelonado 30 to 90; and some trees of Caracas 30 to 50 during one year. Such figures, however, are of very little value, and our purpose can best be served by determining how many cacao fruits must be produced, per tree, to give the same weight of cacao obtainable from 100 fruits of, say, the Cundeamor type.

TABLE VII.

Variety.	Average total weight of cured cacao from 100 fruits.	Number of fruits required to produce cacao of weight equal to that from 100 Cundeamor fruits.
Amelonado ...	4291·35 grs.	95
Cundeamor ...	4097·38 ,,	100
Caracas ...	3994·15 ,,	102
Nicaraguan ...	4340·00 ,,	94

It may be stated that, as far as the *number* of fruits per tree, per year, from each of the above varieties is concerned, the Cundeamor and Amelonado come first, and Caracas and Nicaraguan second; this is only an approximation and does not mean that the order of productiveness of Caracas or Nicaraguan cannot be brought very near to that of the Cundeamor by good cultivation. The highest valued cacao, by weight, is undoubtedly the large plump bean of Nicaraguan and Caracas, then the Cundeamor, and lowest the Amelonado. Judging from current values, the Nicaraguan, Caracas, Cundeamor, and Amelonado cacao may be stated to have approximate values in the ratio of 70, 65, 60, and 50. The Amelonado variety, though it is easily cultivated and gives a good crop, produces thin, flat, bitter, and deep-purple seeds, and seems to be the least desirable to cultivate.

GENERAL CHARACTERS OF VARIETIES OF CACAO.

Having described the nature of the fruit-wall and seeds of different varieties of cacao, it now remains to deal with all the characters under the heading of each variety.

NICARAGUAN.—The trees grow to an average height of 7·6 metres (25 feet) in nine years, and may attain nearly the same dimensions in width. The leaves vary considerably in size. A large proportion of the fruits ripen from December to March, unlike most other varieties in Ceylon. The fruits vary in size and colour; they may be red or green when unripe and reddish-yellow or yellow when ripe; on an

Photo by Ivor Etherington.

NICARAGUAN-CRIOLLO CACAO TREE.

average they measure from 17 to 20 cm. in length, 25 to 28 cm. in circumference, and 10 to 14 mm. in thickness. The seeds are larger than those of Caracas, often weighing twice that of good Caracas seeds; in shape they resemble the Forastero or Amelonado types, being usually much flatter than those of Caracas; in colour they be white, or pale-purple, the majority being white. The seed integument is thin with prominent striæ disposed longitudinally.

Caracas.—This variety is often termed the "Old Red" in Ceylon, and also Criollo and Creole in this and other countries. The stems and branches and, in many cases, the foliage are smaller, than the Forastero varieties; the general appearance of the tree gives one the idea that it is neither as quick-growing nor as hardy as the Forastero. If differs from the Forastero mainly in bearing smaller crops and having fruits with thin soft walls and seeds with thin integuments. The fruits are relatively small, the average length being about 17 cm., circumference 23 cm. and thickness of wall 13mm. The colour is usually red and rarely green when unripe; the fruits are rough on the surface, deeply-grooved, pointed but not acuminate at the apex, and moderately wide at the base. The cured seeds have an average weight of 1.27 grams and have a thin cuticle; the fresh seeds are round and plump and the majority of them white in colour, though purple seeds do frequently occur. Fruits which contain all white seeds belong either to this or the Nicaraguan type.

Forastero or Cundeamor.—The term Cundeamor, in Ceylon, is applied to a Forastero type, largely cultivated on some of the best cacao properties. The fruits are large and measure over 20 cm. in length, and 26 cm. in circumference; the walls are thick, rough on the surface, and deeply furrowed; the apex is usually long and pointed and the base constricted. The colour of the fruit wall is red or green when unripe, reddish-yellow when ripe; the seeds are white or purple. The trees grow quickly and give comparatively heavy crops of elongated rounded seeds of fair quality.

Amelonado.—This variety is said to produce branches which tend to bend towards the ground; it is a quick grower and produces a fair number of fruits per tree. The fruit wall is green when unripe and yellow when ripe in Ceylon, though red forms are known elsewhere; it is thick, hard, and gritty to cut. The fruit is usually short with a broad or slightly constricted base and a blunt apex; the outer wall is not usually deeply grooved and is shiny and smooth. The seeds are thin, flat, and purple, and genuine white seeds are unknown for this variety in Ceylon. The seeds have an average weight of 1·05 grams, and there are usually about 40 to 41 in each fruit; the proportion of integument to kernel is relatively high. There is a form of Amelonado, at Peradeniya, which is characterised by relatively large and long fruits, slightly acute apices, a parti-coloured wall, and deeper groves; the seeds are deep or faint purple in colour, and occasionally slightly rounded.

Calabacillo.—The fruits are smooth and ovate or calabash-shaped and may be red or yellow. This variety is well-known in the West Indies where it is said to produce regular and abundant crops. The seeds are flat, thin, and all purple. It appears to closely resemble the Amelonado type, but its representatives in Ceylon have not yet been satisfactorily identified. According to Hart, this variety is the strongest grower and hardiest type, and will thrive on poor soils and on lands on which it would be impossible to grow the finer kinds of cacao.

Sambito.—There is some doubt as to whether this type occurs in Ceylon, though on the occasion of the visit of Dr. Preuss, trees numbered 5447 and 5735, growing at the Experiment Station, Peradeniya, were pointed out as being closely associated with this type. The particular specimens referred to produced fruits resembling the type of Nicaraguan with red walls and broad base; these fruits contained rounded, white, and purple seeds. It is said to be a common variety in Venezuela, where the characters approach those of the inferior Calabacillo in fruit and seed.

Cacao Blanc.*—This is sometimes spoken of as a hybrid between the Caracas and the red varieties of cacao cultivated in Java. The tree is very vigorous and the seeds are very large; vegetatively this variety is said to show the characters of a Forastero, but a large proportion of the seeds are white in section, and the rest tinted purple. The market price of this variety is said to be very encouraging.

Sangre Tora.—The fruits of this variety are of the typical Forastero type and have a deeply-furrowed wall and blood-red colour; it is grown in Trinidad and will be dealt with later.

Varieties in Trinidad and Grenada.

The numerous varieties found in the West Indies are named and classified by planters and others according to the morphology of the fruits and seeds, the taste of the seeds, and even the country of origin. The names of many of the varieties—such as Amelonado and Calabacillo—have a Spanish origin, but to record the discussions regarding the origin of the names of other kinds would only revive confusion. The main divisions which are recognised in Trinidad are the Criollo, Forastero, and Calabacillo—a rough classification which we have seen to be applicable in Ceylon, if the term Calabacillo is substituted by Amelonado.

Preuss states that the Criollo cacao, in Trinidad, is neither native nor wild but it has been introduced there, and, though it is generally regarded as having remained pure, the characters of the trees, fruits, and seeds are not absolutely constant, and reliable. Much has been written regarding the origin of the name by Trimen,

* Cacao varieties; Le Cacao Blanc de Djati-Roenggo, Journal D' Agriculture Tropicale, Oct., 1901.

Hart, and Preuss and it is obvious from the observations of the latter that in Trinidad, and even in Venezuela which Preuss considers the classical home of Criollo, the term is sometimes applied to more than one variety, and that the names of Forastero, "Cacao del pais", etc., are often confused with it. Preuss maintains that in Trinidad the flat-seeded Trinitario occurs and never the large and rounded Criollo, and that in Venezuela the planters do distinguish between their Criollo and those varieties known as Trinitario or Carupano

The Forastero variety is defined in the narrow sense, by Preuss, as being one characterised by vigorous growth and large leaves, fruits of a large size and possessing deep furrows, rough surfaces, thick walls, and each having a constricted base and a pointed apex. Preuss does not agree with Hart in regarding the Amelonado as a variety of the Forastero group, but maintains that it is an intermediate type between Forastero and Calabacillo. In Ceylon the Amelonado stands out distinctly among all others, and the facts given elsewhere lend some justification for the proposal to completely separate it from other forms in cultivation in Ceylon. The Calabacillo variety in Trinidad is described by Preuss as being small-fruited, thick-shelled and smooth, and possessing flat, thin, bitter, purple seeds; the tree is said to be a quick grower and to possess large leaves.

Cacao Varieties in Central America.

Cacao has long been cultivated in Nicaragua, Salvador, Guatemala and other parts of Central America, and the natives of Mexico claim to have grown it in very remote times. Many varieties have been introduced to various parts of Central America, though it possesses as indigenous species, *Theobroma Cacao, T. bicolor, T. pentagona and T. angustifolia.* The names under which the same or different varieties of cacao are known are confusing, but, thanks to the good work of Preuss, are capable of being arranged in a somewhat satisfactory manner.

Varieties in Nicaragua.

In Nicaragua there are two introduced varieties, known as "Cauca" from Columbia and "Trinitario" from Trinidad, and two indigenous varieties of cacao, termed respectively, "Cacao del-pais" or Criollo and "Lagarto".

"Cauca" cacao differs, according to Preuss, from the Trinitario variety in having much larger fruits and seeds; the fruits are red or yellow, have rough, warty surfaces, and possess violet or white seeds. This kind is mixed and prepared with the Trinitario and then known as "Cacao estrangero", though each variety can be easily distinguished by the differences in size of the seeds.

"Cacao del pais" is distinguished from "Cacao estrangero" on account of its being composed of Lagarto and Criollo seeds, between which no distinction appears to be made; to "Cacao del

pais" the term Criollo alone is rarely given. The Criollo of Nicaragua is, according to Preuss, very similar to that of Venezuela, except that the apex of the Nicaraguan Criollo fruit is sharper and longer, and the fruit walls are thinner; they both have the pointed apex bent towards the stem and are irregular in shape. Nicaraguan-Criollo fruits may be red or yellow and possess from 20 to 28 seeds. The seeds of Nicaraguan-Criollo are, according to Preuss, the largest of all cacao varieties in the world, and certainly those in Ceylon easily beat the record for size; the taste and break of the cured beans are also good, but the aroma is not strikingly so.

The Lagarto fruits are very thin-shelled and may be partly red and partly yellow; according to Preuss, the seeds of the red fruits are bright violet and those of the yellow fruits white.

The Criollo and Lagarto trees of Nicaragua are less vigorous in their woody and foliar tissues than the Trinitario, though they attain a height of about four metres and some specimens yield 1 lb. of dry cacao annually.

Varieties in Salvador and Guatemala.

In Guatemala the cultivation of cacao is said to be carried out more thoroughly than in Nicaragua or Salvador. The varieties grown are described as resembling those in Salvador, and Preuss remarks on the absence of the good Nicaraguan-Criollo on the cacao properties he investigated. The fruits are usually regular in shape and all possible transitions occur between types resembling the Cundeamor and Forastero to the Calabacillo of Trinidad; specimens allied to the Criollo colorado, Lagarto colorado, and L. amarillo are said to occur in Guatemala.

In Salvador the cultivation of cacao extends into the high and low lands. Some of the fruits are described as being deep-red or yellow in colour, and having a rough, warty surface; the seeds are small and round, and may be white and violet in colour if occurring in red-shelled fruits, and white if in yellow fruits.

Varieties in Venezuela.

The cacao in Venezuela is not cultivated on a very extensive and liberal scale, and there is a wide variation in the market value of the different grades of cured cacao. The land planted in cacao is estimated at 25,000 hectares by Benito*. Preuss, who studied the subject on the spot, concluded that the varieties could be roughly classified into two groups, (1) the Criollo and (2) the Trinitario or Carupano, the beans from the former often realising more than twice the value of the latter. The cacao is cultivated mainly along the coast, those plants in the western area being usually considered superior to those on the eastern side, owing to the better quality of soil in the former region.

* Cacao in Venezuela, Der Tro enpflanzer, July, 1901, page 339.

Criollo of Venezuela.

The Criollo types in Venezuela are distinguished by their comparatively weak vegetative system, sparse foliage and small leaves. The fruits are fairly strongly ridged, the surface is very rough, and the apex is long and often curved towards the stem; the wall of the fruit is thin and soft. Preuss, though differing from many others, is emphatic in his statement that the Criollo fruit has not a constricted base, and in appearance suggests a stunted and irregular growth. He also states that in Trinidad there is no cacao of the shape of Venezuela Criollo with white seeds, except that possessed by Hart in the Botanic Gardens. The seeds of the Venezuela Criollo are characteristically large and plump, elliptical or nearly circular in transverse section, and faint bright-purple or white in colour; the taste of the fresh seeds or cured beans is not bitter. The cured beans are light-brown in colour and have a pleasant aroma and taste; the break is such as to allow a skilled tester to detect it by the peculiar rustling noise when pressed in the hand.

The Criollo cacao of Venezuela is recognised as one which requires the minimum period for fermentation. The trees are believed to generally bear their first crops in their sixth or seventh year and their full crops in their ninth or tenth year.

Preuss classifies the Criollo cacao of Venezuela into several sections, the main being (1) Criollo legitimo, (2) Criollo amarillo, and (3) Criollo mestizo.

The Criollo legitimo is considered to be an excellent variety, and trees of this kind constitute 99 per cent. of the best plantations. The fruits are deep-red and the seeds whitish-violet in colour.

The Criollo amarillo is often planted with the former, and has yellow fruits and white seeds.

The Criollo mestizo is only rarely met with, and has fruits which are coloured mainly yellow and a little red.

The Trinitario or Carupano of Venezuela.

The Trinitario or Carupano cacao in Venezuela comprises many sub-varieties, which differ from those of the Criollo group in having better developed and quicker-growing vegetative systems, better foliage and larger leaves; in cropping at an earlier period—usually in their fourth year—and in producing large quantities of cacao of an inferior kind. The varieties, such as the Angoleta and Cundeamor, which have long, strongly-grooved, and rough fruits, yield moderately well in quantity and even in quality, and though inferior to the Criollo they are, in the opinion of Preuss, superior, in every way, to those known as Forastero in Trinidad.

The following sub-varieties are described by Preuss:—(1) Angoleta; (2) Cundeamor legitimo; (3) Cundeamor amarillo; (4) Carupano legitimo; (5) Carupano parcho; (6) Carupano taparito; (7) Sambito; and (8) Trinitario amargo or "Cojon de toro."

The Angoleta cacao is characterised by large, deeply-furrowed, regularly-formed fruits, the walls of which are thick and rough, and the apex attenuate. The seeds are large and plump.

The Cundeamor variety possesses large, deeply-furrowed, rough-walled fruits; the apex is long, pointed, and sometimes bent, and the base constricted. The seeds are darker in colour than the Criollo, and tinged bright-violet; they are large, plump, a little bitter, and ferment comparatively quickly. The Cundeamor legitimo is characterised by red, and the Cundeamor amarillo by yellow, fruits.

The Carupano varieties have usually thick-shelled fruits, containing flat, purple, and bitter seeds. The fruits of Carupano legitimo are mainly red with a little yellow, those of Carupano taparito, yellow or brownish-yellow.

The Sambito variety possesses either red or yellow fruits; the fruit is short with a blunt apex, and the walls are usually thick and fairly smooth. The seeds are seldom very plump, and possess a deep-violet colour and bitter taste.

The Trinitario amargo or Cojon de toro variety has red or reddish-brown fruits which are blunt or shortly accuminate at the apex; the walls are usually thick, smooth, and polished. The seeds are flat, violet, and bitter.

Cacao Varieties in Surinam.

There are three varieties recognised in Surinam, though the names given to them do not indicate varieties in other countries known by the same names. The three principal kinds identified by Preuss were the Surinam, Alligator, and Caracas: in growth, foliage, and habit these varieties do not possess very different characters, though the fruits show differences sufficiently great to admit of their classification. The qualities cultivated in Surinam are ordinary; the seeds are mainly flat, small, and purple.

The Surinam variety is characterised by having short and almost smooth-shelled fruits each with ten flat longitudinal furrows and a constricted base; the fruits are bright-green when unripe and yellow when ripe. It is, according to Preuss, very similar to the Amelonado of Trinidad, and in Surinam is known as the Porcelaine type.

The Alligator variety has a long and strongly-grooved fruit, the base of which is constricted and the surface rough; the fruits are green when unripe and yellow when ripe, This is regarded as being quite different from the real Alligator (Lagarto) variety of Central America, and is related to the type which in Venezuela and Trinidad is termed the Cundeamor.

The fruits of the Caracas variety have a rougher surface than the Surinam; they have thick shells, are deeply furrowed and

pointed. Preuss considers that this is wrongly termed Caracas in Surinam and that it is nearer to the low-valued Veuezuelan kind called the Carupano, and almost identical with the Forastero of Trinidad.

Varieties in Ecuador.

The varieties of cacao cultivated in Ecuador, though not usually of a very high order, are relatively uniform in character, and, according to Preuss, are named after their place of origin rather than the characters of the different plants—hence they are described as Ariba, Balao, and Marchala cacaos, etc. The uniformity in appearance of the cacao plantations is said to be remarkable and to be maintained over very large areas in the flat country bordering the rivers. The fruits are described as being green when unripe, yellow when ripe and as rarely being red in colour; they are plump, thick-shelled, smooth or slightly rough on the surface, and have a slightly constricted base and short apex. The seeds are thicker and fuller than the Amelonado cultivated in Cameroon, Surinam, and Trinidad, but Preuss asserts that they are more closely allied to this variety than any other. Two wild cacaos also occur in Ecuador, namely "Cacao blanco" (*T. bicolor*) and "Cacao del monto" (*Herrania balaënsis*, Preuss.)

Esmeraldas cacao differs from the above in having fruits of a more slender type with long apices, rough surfaces, deep furrows, and somewhat constricted bases, and as thereby resembling the Cundeamor types. The seeds are said to be white and similar to the Criollo amarillo of Venezuela.

Varieties in Samoa.

The original varieties of cacao planted in Samoa were known as Caracas or Criollo, and Forastero, and it has recently been asserted that an offspring has been derived which partakes of the characters of both types. In the publication previously referred to it is stated that "the best variety of cacao to plant is one descended from the trees imported by the German Trading and Planting Company in 1883 and 1884; it is always known in Samoa as Criollo but is quite unlike the Criollo of Trinidad, surpassing it in quality; it is also unlike the Forastero cacao. In fruit, nibs, and form of tree, it most nearly resembles the cacao of Guatemala and Columbia: the beans are said to be as good as the best South American, and to fetch at Hamburg 50 per cent. more than the best cacao from the Cameroons. The pod is of a dark-red colour and about $6\frac{3}{4}$ inches long and $3\frac{1}{4}$ inches thick: a smaller form of pod is of a bright-red colour with orange furrows, and is 6 inches long and $2\frac{3}{4}$ inches (6 inches equal 15·2 cm.) thick." Recently other kinds have been introduced from tropical America and Ceylon, and one may surmise that the mixed nature of the varieties will now be as characteristic of Samoan plantations as it is of others which have been established for many years.

Varieties in Java.

Zehntner has described, in detail, the characters of the varieties of cacao cultivated in Java, and reference should be made to his work by those who desire to gain a deep insight into the question of varieties. Illustrations showing whole fruits, and sections through them, of the following varieties are given:—Java-Criollo, Java-Porcelaine, Nicaraguan-Criollo, Moderboom, Brussel-Cacao, Surinam-cacao, Calabacillo, Cundeamor, Criollo and others grown in the Horticultural Garden, Tjikeumeuh, Buitenzorg.

Varieties in the Gold Coast, Africa.

The plants in the Botanic Gardens, Aburi, are the parents of most of the cacao distributed to, and cultivated by, the natives in the vicinity. Viscount Mountmorres,* in his account of the Gold Coast Department of Agriculture, states that "the species mostly grown is the *Theobroma Cacao*, var. Forastero. Two other kinds which are grown to a much less extent are *T. pentagona* and *T. Cacao*, var. Caracas (white cacao). Neither of these is very satisfactory, however, in supporting the climatic and soil conditions prevailing on the Gold Coast, and in the main the cacao industry of the colony depends almost wholly on the Forastero. Experiments are now being carried on at Aburi to ascertain the effect of grafting *T. pentagona* on to Forastero. The pods of the former are considerably larger than those of the latter, and the beans yield a very much higher grade of cacao when fermented. It is hoped by this grafting to combine the superior quality of the produce obtained from *T. pentagona* and the robustness and hardness of the Forastero stock on which it is grafted."

Varieties in Madagascar.

Foucheré states† that in Madagascar the varieties are very uniform and resemble in seed and fruit characters those of the best Criollo. It is supposed that the Criollo type was introduced from La Réunion and that the latter obtained its supplies from Ceylon, so that the Madagascar Criollo and the Old Red of Ceylon are similar in character to one another and to the original Venezuelan Criollo. Foucheré confirms the statement that much confusion exists in the names applied to the cacao varieties in Trinidad and tropical America.

Colour of Seeds and Fruit Walls.

The relation of the colouring of the seeds to that of the walls of the fruits is interesting. In Ceylon the only variety with wholly violet or purple seeds is the Amelonado which, like one of the Calabacillo types of Trinidad, has yellow fruit walls; the Criollo

* Quarterly Journal, Liverpool University, Institute of Commercial Research in the Tropics. Vol. 1., No. 3, September, 1906.

† Culture Pratique du Cacaoyer, A. Foucheré, Paris, 1906.

specimens in Ceylon and elsewhere which have red-coloured fruit walls are believed to have originally possessed white seeds only, and even now a fair proportion of the fruits of this type possess white seeds only. The Forastero types in Ceylon, with their partly red and partly yellow fruit walls, possess white and purple seeds in various proportions. From these considerations one expects to find in Ceylon that the colour of the seeds is to a certain extent in opposition to that of the fruit walls, red fruit walls enclosing mainly white seeds and yellow fruit walls purple or violet seeds. Preuss, in his travels through South and Central America, records the very opposite of this, and states that the seeds are always white when the fruit wall is yellow, and violet when the fruits are red-shelled, and lays stress on the statement that red-shelled fruits rarely possessed white seeds in the district where he made his very extensive observations, except in Guatemala and Costa Grande.

Preuss records a curious parallelism between the colour of the seeds and the latitude in parts of America visited by him, and points out that the further north he travelled the more predominant became the white colour of the seeds. In Ecuador the seeds were mainly violet, but in northern parts white and violet seeds occurred in Esmeraldas cacao. Cauca cacao of Columbia possessed white or violet seeds, and in Venezuela sporadic Criollo amarillo fruits possessed white seeds. Abundance of white seeds prevailed in Nicaragua and Salvador, and in Guatemala violet seeds were only rarely met with; finally Tobasco cacao had pure white seeds. This, no matter what were the causes, is a most curious condition and worthy of further inquiry.

Natural Improvement of Varieties.

On a plantation where all types of Criollo, Forastero, Amelonado, etc., are cultivated, the characters of the seeds, especially of the Criollo and Forastero groups, become intermingled. Varieties, which at one time were supposed to possess fruits with white seeds or purple seeds only, show both kinds in various proportions, and on a typical estate in Ceylon today, it would be impossible to find a pure white-seeded variety, though types with entirely purple seeds are recognisable. It is therefore obvious that, if the mixed seed character is due to hybridisation, the capacity for improvement or degeneration varies with the variety and in a mixed plantation would be difficult to control.

When, however, only one variety is cultivated there appears to be a recognisable change during the life history of each, and it has often been questioned whether by careful cultivation and seed selection, a Criollo-like form could not be evolved from one of the Cundeamor type or vice versa. Some varieties appear to exhaust themselves and the soil much quicker when planted alone than when interplanted with leguminous shade trees; others appear to thrive equally well, with or without shade trees, when

once they have attained the full bearing stage. In Venezuela it is stated that the Sambito variety improves in size of seeds, but retains its thick fruit walls with advancing age, whereas the Trinitario amargo variety, singular among all others, is unable to improve its qualities, but remains bad or degenerates, and soon exhausts the soil around it.

From these and other considerations it has been suggested that it may be possible to effect a gradual improvement in the Nicaraguan, Old Red, and Cundeamor varieties in Ceylon much quicker then in the more cosmopolitan and inferior Amelonado; in the average mixed plantation most varieties appear, as far as seed characteristics are concerned, to be approximating nearer to the Forastero than to any other type. The percentage of Criollo fruits with white seeds only, and the proportion of white and purple seeds in the same class, are of considerable interest in connection with this subject.

Seed Selection for Cacao.

It is obvious from the foregoing accounts that a large number of varieties exist, and the selection of seed parents is consequently rendered very difficult. Certain types appear to succeed on soils and in climates having distinctive characters; but when the type has been fixed upon, the selection of seed parents is mainly a matter of observing the healthiness and productiveness of trees of the selected types and using seeds only from the best trees. It is usual to allow the fruits to remain on the selected trees as long as possible and to discard the small seeds which sometimes occur at the ends of the fruits; in some cases only the largest and heaviest seeds in the middle of each fruit are selected for seed purposes, those weighing below the standard fixed being used for other purposes.

The productiveness of cacao trees can be easily determined by numbering the trees under observation and keeping an account of the fruits which reach maturity. As examples of cacao trees used for seeds parents at Peradeniya may be mentioned some which have given 187, 172, and 125 fruits in two to three months and one which gave over 400 fruits in one year. The productiveness varies from year to year, and for this reason the observations should be continuous in order that the weaker and more variable trees may be eliminated. Cacao lends itself to seed selection to a remarkable degree, and on such work must largely depend the future of the industry.

The seed parent trees should, if possible, be selected from areas where only one variety exists in order to make certain that there has not been cross fertilisation with inferior types: otherwise it may be necessary to pollinate by hand, an operation which is rarely attended with success in connection with cacao, on account of the very small percentage of flowers which produce ripe fruits.

CHAPTER V.

PERIODICITY OF THE CACAO TREE.

IT is necessary to consider the periodicity of the vegetative and reproductive systems of the cacao tree before dealing with the subject of its cultivation and the harvesting of its crop. There are reasons for believing that the most successful results in cultivation will probably be obtained by taking advantage of the normal periods of varying activity which characterise the different stages in the life of the tree rather than by the adoption of methods or the application of substances to stimulate parts of the tree during their periods of rest.

The cacao trees on a large area produce leaves, roots, flowers, and fruits throughout every month of the year, and many cultivators have adopted methods with the idea of making the trees more productive at periods of the year which do not agree with those of the natural periodicities. It is possible, by affecting the water supply to the roots, and by the pruning of branches and roots, to considerably change the periodicity of vegetative and sexual tissues, but it is a course which, if not carried out very carefully, may be accompanied by a serious reduction in the cacao crop.

Foliar and Root Periodicities.

In all tropical areas heat and light are intense, and these, together with the heavy rainfall of many places, allow of a conspicuous growth of vegetation at most times of the year. Though the climatic changes are not analagous to the seasons of a temperate region, the plants in the tropics are just as subject to periodical changes of rest and activity as those of cooler zones. The periodicities of the climates in cacao-growing countries differ considerably, and the remarks here given have reference mainly to the cacao trees in the Peradeniya district of Ceylon. A change in climatic periodicity is usually followed by a difference in plant periodicity. The leaves of the cacao tree show an increase in number year by year until by about the eighth or tenth year a standard size appears to be attained. Throughout these earlier years the foliar production is irregular, but as time goes on there is a tendency to produce a large number of new leaves during two or three periods each year. On a cacao estate with all the trees in bearing it is impossible to find a healthy specimen absolutely leafless even during the hottest and driest part of the year; most of the trees produce a few leaves every month in the year, but reserve

their periods of maximum foliarp roduction for the months of February, March, and September, considerations to be kept in mind when dealing with the periodicity of the flowers and manuring operations. The periodicity in the root growth of cacao trees in Ceylon is but little understood; the rootlets are formed during almost every month in the year, but during April-June, and again in October-November there appears to be increased activity in this part of the plant. The general observations made on this part of the subject point to a periodicity of root activity in association with that of the foliage.

Flower Periodicity.

An investigation has been made on the periodicity of flower production with a view of determining its relationship to that of the fruits and rainfall. Forty-two trees were under observation each day in the years 1903, 1904, and 1905. The flowers were plucked after they had opened, so that the physiology of the plant would be disturbed as little as possible. It may be asserted that the removal of these newly-opened flowers would probably lead to a more prolific appearance of flowers at a subsequent date, but when one considers that an average tree produces only about sixty to eighty mature fruits in the whole year, the procedure adopted cannot be expected to greatly alter the flower periodicity in question. Not more than 0.2 to 0.4 per cent. of the flowers produced on a cacao estate planted 12 × 12 feet, and yielding 3 cwt. of cacao per acre, per year, develop into mature fruits; they are easily detached when in full bloom or after withering.

Flower Periodicity for 1903.

The number of flowers produced in the year 1903 varied from 178 on tree number 5,725, to 33,534 on tree number 5,782.

The average number of flowers produced, per tree, for 1903 was 5,666, equal to $1\frac{3}{4}$ million per acre. In order to show the variability the following figures are quoted for six selected trees:—

Month.	Tree No. 71	Tree No. 5,786	Tree No. 5,782	Tree No. 5,768	Tree No. 5,798	Tree No. 5,434
January ...	67	65	165	113	127	43
February ...	388	245	353	34	17	7
March ...	1,992	372	4,269	479	704	91
April ...	1,292	438	4,578	334	1,428	33
May ...	2,978	2,439	7,050	1,507	7,605	641
June ...	1,576	756	1,531	150	495	144
July ...	1,950	1,829	3,509	272	476	123
August ...	1,391	442	2,148	214	193	97
September ...	1,285	423	3,778	595	308	60
October ...	1,246	755	3,376	445	89	36
November ...	1,192	496	1,639	232	63	15
December ...	998	944	1,138	276	52	26
Total ...	16,355	9,204	33,534	4,651	11,457	1,316

The following table gives (1) the total number of flowers produced on the forty-two trees under observation; (2) the monthly average of flowers per tree for the year 1903.

Month.	Total Flowers for forty-two trees.	Average No. of flowers per tree.
January	4,281	102
February...	4,616	109
March	25,562	608
April	18,616	443
May	71,839	1,710
June	14,982	356
July	21,811	519
August	15,347	365
September	21,124	503
October	17,191	409
November	11,080	264
December	11,556	275
Total... ...	238,005	—

Flower Periodicity for 1904.

The observations were continued on the same trees as in 1903; the following are the records showing (1) the total number of flowers produced on the forty-two trees under observation (2) the monthly average of flowers per tree during 1904:—

Months.	Total Flowers for 42 trees. 1904.	Average No. of Flowers per tree. 1904.	Average No. of Flowers per tree. 1903.
January ...	11,799	280	102
February ...	12,953	308	109
March ...	29,250	696	608
April ...	57,287	1,363	443
May ...	84,011	2,000	1,710
June ...	84,338	2,008	356
July ...	32,345	770	519
August ...	11,326	269	365
September ...	15,567	370	503
October ...	24,852	591	409
November ...	19,971	475	264
December ...	17,791	423	275
Total ...	401,490	9,553	5,663

The average number of flowers produced, per tree, for 1903 was 5,663, equal to $1\frac{3}{4}$ million per acre at 300 trees to the acre The average number of flowers, per tree, for 1904, was 9,553 equal to $2\frac{4}{5}$ million per acre per year. In 1904 the trees were much freer from disease. An interesting case was observed on tree numbered 4,031 on plot 3. This tree produced flowers every month in the year, but on the 20th June, 1901, it possessed no less

than 27,632 flowers, the counting of which occupied the attention of two men 1½ days. On the 20th July there were only fifteen young fruits on the same tree, and through the year the tree did not produce one hundred fruits.

In order to show the variability during 1904, the following figures are quoted for six selected trees :—

Months.	Tree No. 71.	Tree No. 5786.	Tree No. 5782.	Tree No. 5768.	Tree No. 5798.	Tree No. 5434.
January ...	1,036	674	1,429	296	110	34
February ...	1,074	929	1,505	257	1,191	46
March ...	2,764	1,547	3,191	820	284	160
April ...	5,032	3,048	5,076	1,944	600	379
May ...	9,079	3,256	9,875	2,744	1,529	509
June ...	9,508	5,499	7,793	2,127	1,241	756
July ...	2,898	1,743	1,537	963	525	522
August ...	1,376	391	1,189	201	130	57
September ...	1,519	666	1,836	187	153	149
October ...	2,232	1,017	2,953	444	234	203
November ...	1,973	674	2,051	376	213	54
December ...	1,335	572	1,333	411	204	62
Total ...	39,826	20,016	39,768	10,770	6,414	2,931
Total for the same trees during 1903	16,355	9,204	33,534	4,651	11,457	1,316

The data for the flower production during 1905 on the same trees, is now given for comparison with previous years.

Monthly Flower Periodicity for 1905.

Months.	Total flowers for 42 trees.	Average number of flowers per tree.		
	1905.	1905.	1904.	1903.
January ...	13,524	322	280	102
February ...	15,893	378	308	109
March ...	19,773	470	696	608
April ...	19,999	476	1,363	443
May ...	55,752	1,327	2,000	1,710
June ...	157,913	3,759	2,008	356
July ...	50,730	1,207	770	519
August ...	25,354	603	269	365
September ...	10,697	254	370	503
October ...	5,650	134	591	409
November ...	40,946	974	475	264
December ...	88,879	2,116	423	275
Total ...	505,110	12,020	9,553	,369 5

5435

Number of Cacao Flowers on Estates.

These observations prove that there is not a month in the year when flowers are not produced if a minimum of, say, ten trees is chosen. On six out of the forty-two trees selected no flowers were produced during certain months of 1903, these months including only February, March, and April.

The total number of flowers produced on a cacao estate may be estimated at from 1,700,000 to 3,606,000 per acre, per year (300 trees to the acre). A yield of 3 cwt. of cured cacao per acre means that at the most only about 8,000 flowers develop into mature fruits on each acre per year, or, in other words, a balance of 1,692,000 to nearly 3,600,000 flowers, per acre, per year, are of no value to the average cacao planter. A large number of flowers appear to be fertilised, but the expanding fruits soon turn yellow and shrivel; for the year 1903 out of a total of 569,738 promising fruits, no less than 288,205 were of this class.

These facts show that there is ample opportunity for research in connection with flower pollination and fertilisation. The cacao trees on which these observations were carried out were normal; it would have been possible to select much more vigorous plants, and to show that the average number of flowers produced was in excess of those under observation for that year. For the present it is important to note that the period for maximum flower production was in the months of April, May, and June, and that this was preceded or followed by minor periods of floral activity in the years 1903, 1904, and 1905.

Periodicity of Fruit Production.

The first point to discuss in connection with this subject is the relation of the flower to the fruit periodicity.

For the present we will confine ourselves to a comparison of the crop progression and floral periodicity for the year 1903.

If the flowers produced each month have relatively the same fruit-producing capabilities, the crop progression curve should show minor periods of activity in association with the minor floral activities in March, July, and September, and a large increase associated with the month of May—the flower month of that year. The observations show that a minor activity in flower production in March was followed by a rise in fruit production in August (five months' interval), and that the fall in flower production in April was followed by a decline in fruit production in September (five months' interval). It further shows that flower production was more active in May than in any other month of the year, and the great rise in the flower curve was followed by a conspicuous rise in the crop curve for October and November (five to six months' interval). It is believed by many planters that the fruit is not

derived so much from the flowers which appear abundantly at one time, as from those produced during the preceding or succeeding periods of minor activity.

Effect of Increased Flower Production.

Though it is commonly admitted that the maximum crop of ripe fruit is not always associated with that of the flowers in the same year, it is of interest to record that an increased flower production has, on cacao recovering from the effects of disease, been accompanied by a regular increase in crop gathered, though, throughout the change, only 0.2 to 0.4 per cent. of the flowers produced mature fruit. In the table given below it is obvious that while progressive improvement in flower and fruit production occurred in the years, 1903, 1904, and 1905 the number of flowers which never produced mature fruits showed an increase with that of the total flower production; an increase of nearly two million flowers, per acre, in the year 1905 over that of 1903, was only accompanied by an increase of about five thousand mature fruits, per acre, in 1905 as against 1903. It is an interesting generalisation that on a gradually improving cacao plantation, allowing for 300 trees per acre, approximately one cwt. of cured cacao has been obtained from the fruit arising from one million flowers.

Relation of Fruit to Flower Periodicities.

Year.	Average No. of flowers per tree.	Average No. of flowers per acre of 300 trees.	Average yield of cured cacao in cwt. per acre.
1903 ...	5,663	$1\frac{3}{4}$ million	1.18
1904 ...	9,553	$2\frac{4}{5}$,,	2.07
1905 ...	12,020	$3\frac{3}{5}$,,	3.57

Flower Pruning.

It has now been proved that the cacao trees at Peradeniya, and probably in all countries where they are cultivated, produce a very large number of apparently useless flowers. In the production of flowers a large quantity of essential food ingredients is used up, and it is questionable whether a certain amount of flower pruning might not be adopted with some hope of success. At the same time it is necessary to point out that not one per cent. of the cacao flowers can ever be expected to regularly produce fruits, and this apparently wasteful flower production is only very similar to what frequently occurs on other fruit-producing trees under cultivation.

Periodicity in Fruit Production: 1902-1906.

We can now consider the monthly periodicity of the cacao crop during 1902, 1903, 1904, 1905, and 1906,—periods accompanied

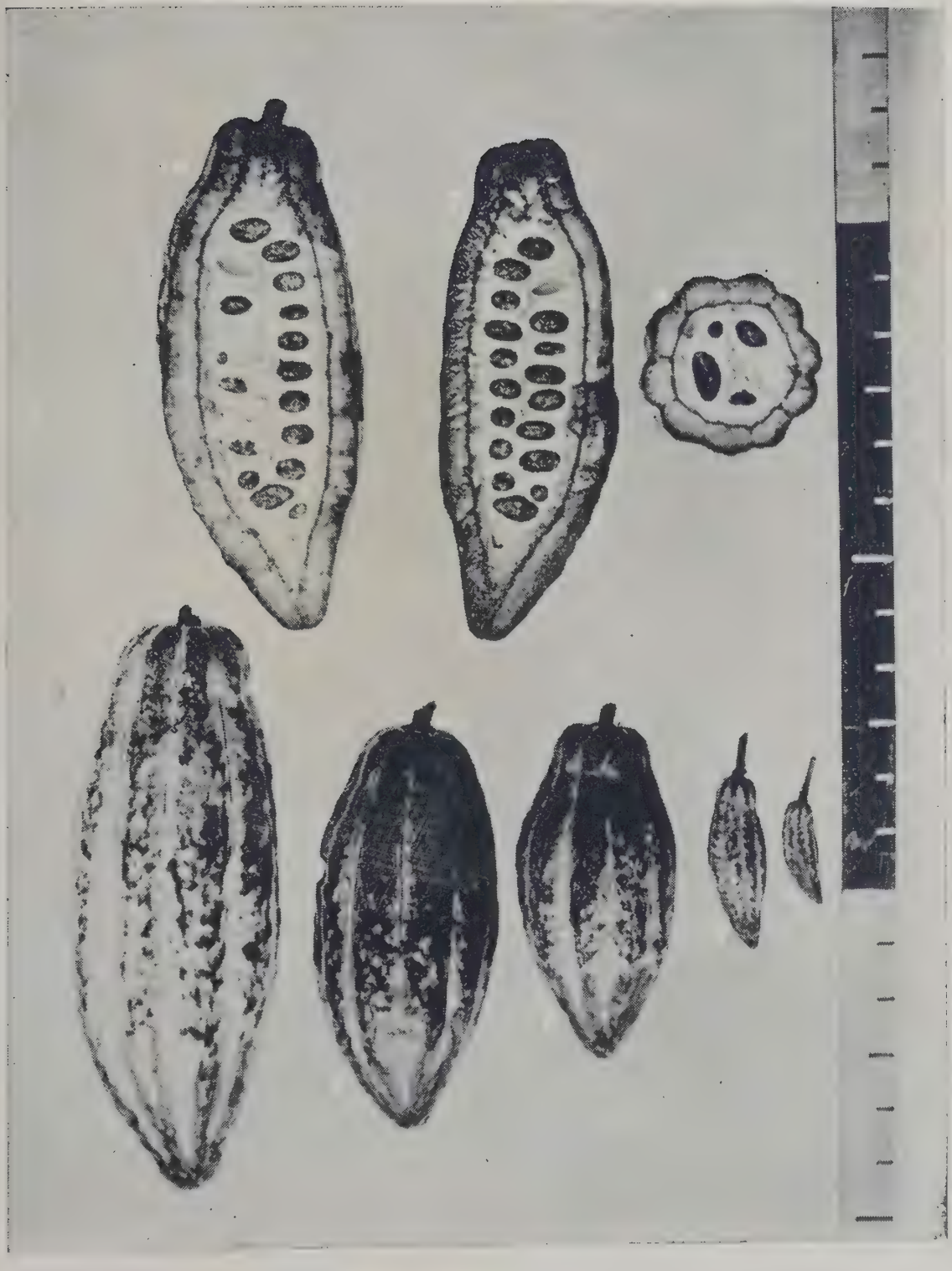

Photo by H. F. Macmillan.

DEVELOPMENT AND STRUCTURE OF CACAO FRUITS.

1–5 Cacao fruits of different ages; 1 (one week); 2 (two weeks); 3 (six weeks); 4 (ten weeks); 5 (17 weeks):

Longitudinal (6 and 7) and transverse sections (8) through ripe fruits, showing white and coloured seeds *in situ*.

by a gradual reduction in parasitic diseases on the cacao and progressive increase in the yield of cacao fruits. The results obtained are of value, botanically and commercially, as they have been obtained on a cacao plantation over one hundred acres in extent and may therefore be accepted as good averages, free from some, but not all, the unavoidable errors associated with records and deductions from the customary one-acre plots, which figure in the accounts of most experimental work.

PERIODICITY OF THE CACAO CROP FROM MAY 1902 TO MARCH 1903.

Month.		Good.	Fungus.	Squirrel.	Green.	Dried.	Total.
April	1902 ...	—	—	—	—	—	—
May	,, ...	10,600	2,193	1,470	—	—	14,263
June	,, ...	4,777	2,073	1.409	—	8,050	16,309
July	,, ...	2,202	3,916	412	—	291,237	297,767
August	,, ...	2,634	5,161	533	4,555	22,979	35,862
Sept.	,, ...	12,413	22,547	1,614	7,850	23,657	68,081
Oct.	,, ...	47,564	26,514	4,186	12,272	509	91,045
Nov.	,, ...	47,467	21,187	6,708	5,878	1,402	82,642
Dec.	,, ...	13,615	5,174	3,047	2,332	2,310	26,478
Jan.	1903 ...	5,620	687	3,240	1,616	2,977	14,140
Feb.	,, ...	2,569	151	3,576	1,207	3,351	10,854
March	,, ...	1,807	117	2,554	729	5,318	10,525
	Total ...	151,268	89,720	28,749	36,439	361,790	667,966

PERIODICITY OF THE CACAO CROP FROM APRIL 1903 TO MARCH 1904.

Month.		Good.	Fungus.	Squirrel.	Green.	Dried.	Total.
April	1903 ...	1,956	37	1,913	402	7,450	11,758
May	,, ...	1,124	36	1,022	290	24,134	26,606
June	,, ...	885	41	465	533	9,446	11,370
July	,, ...	2,270	121	630	422	19,226	22,669
August	,, ...	5,739	235	1,359	442	65,001	72,776
Sept.	,, ...	3,162	773	1,758	2,796	67,505	75,994
Oct.	,, ...	13,002	4,862	4,325	1,680	57,232	81,101
Nov.	,, ...	105,008	10,422	6,726	1,929	16,100	140,185
Dec.	,, ...	70,247	3,323	6,413	1,312	10,465	91,760
Jan.	1904 ...	78,513	1,058	8,171	245	7,200	95,187
Feb.	,, ...	14,369	251	3,075	189	3,470	21,354
March	,, ...	8,541	141	3,224	192	16,004	28,102
	Total ...	304,816	21,300	39,081	10,432	303,233	678,862

Periodicity of the Cacao Crop from April 1904 to March 1905.

Month.	Good.	Fungus.	Squirrel.	Green.	Dried.	Total.
April 1904 ...	17,873	136	5,327	221	15,020	38,577
May ,, ...	12,410	92	2,089	149	5,265	20,005
June ,, ...	13,271	1,461	4,728	135	7,929	27,524
July ,, ...	2,204	916	1,239	120	12,519	16,998
August ,, ...	1,360	1,090	1,161	3,694	25,092	32,397
Sept. ,, ...	14,569	2,317	3,905	2,543	43,356	66,690
Oct. ,, ...	76,200	3,813	4,057	1,017	12,741	97,828
Nov. ,, ...	55,831	4,528	2,242	612	7,529	70,742
Dec. ,, ...	85,750	3,547	859	697	13,054	103,907
Jan. 1905 ...	92,245	2,225	2,670	677	11,402	109,219
Feb. ,, ...	28,533	393	1,825	609	8,118	39,478
March ,, ...	8,858	179	1,197	1,620	11,157	23,011
Total ...	409,104	20,697	31,299	12,094	173,182	646,376

Periodicity of the Cacao crop from April 1905 to March 1906,

Month.	Good.	Fungus.	Squirrel.	Green.	Dried.	Total.
April 1905 ...	37,737	469	1,590	222	9,152	49,170
May ,, ...	36,782	562	1,218	76	5,313	43,951
June ,, ...	10,831	228	400	218	2,349	14,026
July ,, ...	12,115	579	1,118	135	15,265	29,212
August ,, ...	5,338	915	1,168	771	154,650	162,842
Sept. ,, ...	24,119	1,869	2,075	714	198,482	227,259
Oct. ,, ...	84,588	4,173	2,999	—	56,012	147,772
Nov. ,, ...	243,223	3,274	3,779	289	20,090	270,655
Dec. , ...	93,010	2,332	4,187	158	12,639	112,326
Jan. 1906 ...	44,773	942	6,107	14	6,356	58,192
Feb. ,, ...	9,343	649	2,221	44	2,536	14,793
March ,, ...	15,175	932	4,300	10	4,029	24,446
Total ...	617,034	16,924	31,162	2,651	486,873	1,154,644

These are the records of fruits of all kinds obtained from plots of cacao comprising many varieties and from a plantation varying from 100 to 150 acres in extent. The green fruits were derived from branches of the cacao removed during plant sanitation and pruning operations; the dried fruits are an interesting series and will be dealt with separately; for the present only the actual periodicity of the mature fruits during the years under review need be considered.

Periodicity of Mature Fruits at Peradeniya.

In most parts of Ceylon a spring crop is harvested during April to June, but from the records of fruits collected at the Experiment Station, Peradeniya, it is clear that the crop harvested prior to October is usually insignificant. In the year 1902 the maximum crop was harvested in October and November, in 1903-04 in November to January, in 1904-05 during October to January, and in 1905-06 the month of November was remarkable for the heavy crop harvested. The rapidity with which the fruits ripen appears to be dependent on the nature of the weather in the latter part of the year, dry weather apparently hastening the ripening. This is well seen by comparing the monthly rainfall during the years 1902 to 1906 with the monthly crop harvested during the same period; the small rainfall for November in 1903 and 1905 coincides with a very heavy and conspicuous cacao crop. The differences observable in the periodicity of the crop at Peradeniya cannot be entirely explained in terms of the variability in climate, but must also be associated with the gradually improving condition of the plantation where the observations were made.

Periodicity in Dried Fruits.

The setting of the young cacao fruits in May to August is generally anxiously watched by the cultivator in order that he may be able to obtain some idea of the probable harvests for the year. But the manner in which thousands of these fruits commence to dry up, after they have attained a considerable size, is sometimes appaling; the dying back may be due to lack of nutrition, attacks of fungi, or perhaps explainable as instances of succulence without fertilisation. The periodicities here recorded show the months which are notable for the large number of these fruits, and spraying and manurial operations might advantageously be carried out in association with these periods of setting and dying back of the young fruits. This point does not appear to have attracted much attention up to the present, but if the cultivators will only realise that over one and a quarter millions of such fruits occur on one hundred acres in four years, the matter may receive the attention it deserves.

Artificial Pollination of Cacao Flowers.

If the dying back of the young fruits is traceable to the pistil having first expanded, independently of fertilisation, it is doubtful whether manuring to supply food materials or spraying to ward off the attacks of fungi will have any direct beneficial effects. Many of the fruits which die back first undergo a change in colour, usually becoming yellow or yellowish-red, and finally shrivel and shrink until they are about one-fifth their original size; if such fruits are cut when the first indications of dying back appear, it will be noticed that though the position of each seed and its area is outlined, there are no signs of an embryo in most specimens. Such instances may be regarded as cases of succulence without fertilisation and though

such developments are the acme of edible fruit cultivators, the production of seedless cacao fruits has no attraction to most cacao planters; pollination by hand or the spraying of solutions wherein pollen grains can grow, may result in more frequent fertilisation and the production of a larger proportion of mature or seeded cacao fruits.

On the other hand, many cases have beeen observed where numerous and very large clusters of young cacao fruits have begun to set, but where the local food supplies appear to have been deficient, and dying back was inevitable; others have been known to die back on account of being attacked with parasitic fungi: in such cases manuring and spraying may prove beneficial.

Crop Periodicity in Tropical America and Africa.

Though in most parts of tropical America the flowers are produced all the year round, as in Ceylon, yet definite periods are recognised for the harvesting of the crops. In most countries the cacao crop is usually conspicuous on two occasions each year, the spring or Easter harvest being generally a forerunner of a heavier crop to be collected some four to six months later. In Ecuador the chief harvest times are, for Arriba, from March to June and occasionally in January: in Balao and Machala the crops are ripe from August to November and sometimes in April. According to Jumelle, in the Antilles one of the crop periods—the Easter—corresponds to the months of April, May, and June: the other corresponds to the months of November, December, and January, and is known as the Xmas harvest; this is generally the best.

In Venezuela, the Xmas harvest, (a third superior to the other) is in November, December, and January; and the Easter harvest in July and August. In Mexico the principal harvest is in March and April; there is a small one in October.

In most parts of Brazil the winter harvest, which is usually a heavy one, corresponds to the months of June and July; the summer one does not begin till January or February.

On the West Coast of Africa at San Thomé, in Cameroon, and in the Congo, the big harvest usually takes place in August, September, and October at the end of the dry season; there is also a small one in December and January.

In Trinidad* there are two principal harvests in each year, one in May to June and another in November to December, together with minor harvests during the other months.

* L' Agriculture Pratique des Pays Chauds, Nov.-Dec., 1903: Etudes et Memoires, La Trinidad, by Gratien Candace.

CHAPTER VI.

THE CULTIVATION OF CACAO.

THE first point to consider in connection with the cultivation of cacao is the climate. Different countries appear to have obtained almost contradictory results as far as the most desirable elevation is concerned, though most of them agree in indicating that cacao requires a fairly good rainfall ranging from 1270 to 3000 mm. (50 to 120 inches) per year, an average annual mean temperature between 23·9 and 26·7° C. (75° and 80° F.), and a climate which is not characterised by long recurring periods of drought. In general, the climate required for cacao cultivation is somewhat similar to that for Para rubber. When cacao was first introduced to Ceylon, most planters were, to some extent, guided by the results previously obtained in Trinidad—the home of most of the original Ceylon cacao, —and concluded that this product was best suited for estates little above sea-level. At the present time only a few scattered trees of cacao are to be found in the low-country districts below two hundred feet; the remaining specimens at Baddegama, Henaratgoda, in the Kalutara, Bentota, Ambalangoda and other districts, lack the vitality natural to the trees when under proper cultivation. Most of the Ceylon cacao estates of repute are at elevations ranging between 300 and 600 metres (roughly one and two thousand feet) in the Kadugannawa, Kandy, Dumbara, Matale, and Uva districts, though plantations of importance are to be met with below 300 metres in the Uva and Central Provinces of Ceylon. A glance at the tables of temperature, rainfall, humidity, and elevation given elsewhere will indicate the range in climatic factors in cacao-growing countries.

According to Jumelle if the average air temperature is below 24° C. or the minimum temperature below 10° C. cacao cultivation is not a success; where the rainfall does not amount to more than 1·60 metres cacao cannot be grown successfully. Chevalier* states that the average temperature should not be above 30° C. or ever below 20° C.

Altitude for Cacao.

In Venezuela, cacao is grown at an elevation of 600 to 800 metres; in San Thomé, cacao estates flourish, according to Chalot, at an elevation of 300 metres. It is only in the equatorial region that cacao can be grown at such high altitudes; generally better

* Les Exigences naturelles du Cacaoyer, by M. Aug. Chevalier, Journal D'Agriculture Tropicale, Oct., 1906, p. 319.

results are obtained at altitudes in the equatorial zone which are 200 metres (655 feet) or less. The cacao tree grows wild in tropical America where the temperature is high and the soil and air moist. Boussingault states that on some cacao estates the hygrometer showed that in the middle of the day the air was almost saturated with moisture.

Preuss, who has done a considerable amount of travelling states that cacao can generally be successfully cultivated at altitudes from sea-level to 900 metres above sea-level. He states that the finest Criollo cacao cannot be successfully grown much above 400 metres, that Forastero or medium varieties may thrive up to 600 metres, and that above 600 metres only the less valuable and stronger varieties such as the Amelonado and Calabacillo can be successfully cultivated.

Cacao Cultivation in Tropical America.

Venezuela.—The cultivation of cacao in Venezuela is apparently not carried out on very advanced lines. Holing before planting is not customary, and appears to be done only on a few estates; the distance adopted for the plants is about three metres (nearly ten feet) or less, and the seedlings are usually raised in nurseries. In clearing operations all the trees are felled, and a temporary shade of banana, maize, and other plants is used during the early stages. A considerable amount of cacao is used locally; often the beans are roasted and eaten, but a large proportion, especially of the Carupano variety, is said to be used in the manufacture of chocolate.

Surinam.—According to Preuss it is not customary, in Surinam, to thoroughly hole before planting, and the plants are usually distanced from 4 to 6 metres apart. If more than one seed or plant is put in one hole, the estate is subsequently thinned-out so as to allow one tree to remain in possession of each original planting area. Manuring is not carried out extensively, though the pruning of the cacao trees and the thinning-out of the shade trees receive occasional attention. The cacao trees begin to bear fruits in their fourth, and produce good crops in their seventh year; the average annual crop, per tree, is said to weigh about three pounds.

Ecuador.—The planters in Ecuador often find, when carrying out clearing operations, large numbers of wild cacao trees, which Preuss believes to be indigenous to that part of South America, but which many others regard as having been distributed through the agency of monkeys and squirrels from cultivated plantations in adjacent districts. These wild trees are described as being very similar to the cultivated ones and as yielding equally good fruits, though the seeds have thicker integuments. These trees are not felled by the planters, but are retained, often together with other fruit trees, palms, and rubber plants, which grow wild in the neighbourhood. Before planting, the estates often consist, according to Preuss, of a large number of wild cacao trees, and others of *Inga edulis*, *Sapium utile*, *Castilloa elastica* and *Chrysophyllum Cainito*, etc

Holing is not as neceesary as in most other countries with less fertile soils, and is to a large extent neglected; drains and roads, as well as pruning and manuring, appear to be neglected to an undesirable degree on many plantations. The cacao seeds are often planted as many as five at one point with the result that many of the properties subsequently develop into what are described as "cacao thickets." The stems grow to a height of 8 metres, the trees are usually closely planted, and are not systematically pruned to form well-forked symmetrical plants. Shade trees such as *Erythrina glauca* are largely planted, and also a few of *E. amasisa*, which, together with the trees that have been spared in felling operations, constitute the shade for the young and old plants. The cacao trees under cultivation begin to bear fruits in their fourth year and give full yields, according to Preuss, in the sixth to the tenth year.

Preuss* states that not very much cacao is cultivated in Guatemala, and, though it grows well and is of good quality, it is inferior to that met with in Nicaragua. *Castilloa elastica* is often used as a shade for cacao in this country, but not always with very good results.

Cacao Cultivation in Trinidad and Grenada.

Among British possessions Trinidad and Grenada are two of the most important centres for cacao, and compare very favourably with San Domingo and Venezuela. In Trinidad most estates are well supplied with shade trees, the leaves and flowers of which effectively protect and enrich the soil, but in parts of Grenada, where the rainfall is greater than in Trinidad, there does not appear to be the same necessity for the shade trees. The cacao is more extensively cultivated in Trinidad than in Grenada, though in the latter place manuring is largely adopted; in Trinidad the cacao trees are described as beginning to give good harvests in their tenth year and continuing to do so without manuring, but in Grenada, where the cacao trees yield fairly good harvests in their fifth year, the crop is said to fall off considerably in ten or twelve years if manuring is not carried out. Preuss states that the average yield of cacao in Trinidad may be accepted at $1\frac{1}{2}$ to $1\frac{3}{5}$ lb. of cacao per tree, per year, and that of Grenada a little higher than this, but the Trinidad cacao which is largely of the Forastero type fetches a higher price than that from Grenada which is mainly Amelonado. The yields are also often associated with the shade trees used in both countries.

It is generally maintained that cacao trees grown without shade exhaust the soil and themselves quicker than when grown with shade, especially when planted closely; the average harvests in Grenada are larger than those in Trinidad, but they soon fall off if manuring is not carried out, a phenomenon which has often been associated with the fewness of shade trees cultivated on cacao plantations in Grenada as compared to Trinidad.

* Preuss, Reisebericht aus Centralamerika; Der Tropenpflanzer, Dec., 1900

Cacao Cultivation in Java.

It is generally agreed that cacao cultivation in Java has recently increased at the expense of coffee.

Originally the delicate Criollo variety was mainly cultivated, but now the planters are also using Forastero varieties as they believe that the latter are not likely to suffer as much from the attacks of Helopeltis and the boring beetle. The Forastero variety grows well at about 23 to 550 metres (75 to 1800 feet) above sea-level and gives good yields.

The cacao is being largely planted between the existing coffee, and it is stated that after four years even the Liberian coffee trees are appreciably affected.

Growth of the Cacao Tree.

The cacao seeds, after having been partially dried by exposure to the sun or rolling in earth, germinate within a few days of being sown, if favourable weather exists. The cotyledons soon appear above the ground, and in four or five months the young cacao plant possesses a good lateral root system, several inches in diameter, and a stem six or more inches (15 cm.) high with over half-a-dozen relatively large leaves. Subsequently the stem and tap root increase considerably in length until by the end of the third or fourth year, when the trees are beginning to blossom for the first time, the tree has a main stem 2·4 to 3·3 metres (eight to eleven feet) in height, and a foliar system measuring from 1·2 to 3 metres (four to ten feet) in diameter. Cacao trees commence to bear in 3, 4, 5 or 6 years; they are at their best in about the 10th. or 12th. year and continue to flourish up to 20 or 25 years. After 25 years the crop is said to diminish; one property in Trinidad is said to have cacao trees 100 years old still bearing good crops.

There is a nett increase in all the vegetative parts of the plant for the first few years, and the flower production usually increases from year to year. The trees first flower in their third or fourth year, and a more or less regular crop may be relied upon after the fourth or fifth years. After the eighth or tenth year the trees increase in size less rapidly. Trees, when twenty to thirty-five years old, possess all the characters indicative of sound internal tissues, and by some sanguine authorities it is asserted that the cacao trees may, by cultivation, be kept in a productive state for over a hundred years. Mature trees vary in height from 3·6 to 7·6 metres (12 to 25 feet) and in diameter are about the same; in Trinidad they are reported to be fifteen to twenty feet in height, and in Grenada, Tobago, and St. Vincent to be much smaller than those in Trinidad.

Land, Drainage, and Roads.

Selection of Land.—The cacao tree is cultivated in soils differing widely in mechanical and physical properties, and seems to grow nearly as well on sloping banks as on flat alluvial land.

In Ceylon the cacao soils are never very rich from a chemical standpoint, but the cacao thrives well when good mechanical properties exist and where the climate is favourable. The alluvial or finely-divided loamy soils in Ceylon, such as those on the flat part of the Experiment Station, Peradeniya, bordering the river, are very suitable for cacao; in Trinidad loose clay, or clay with an admixture of a fair proportion of sand and lime, is considered to be favourable to the growth of cacao. Unlike other arborescent products such as Hevea brasilensis, the cacao tree does not appear to thrive in swampy soils, even when the latter are well-drained and limed. Cacao estates composed entirely of stony or hilly land with steep faces do not generally obtain as successful results as those laid out on more gently undulating or flat land, though in all cases cultivation is generally possible. Windy places should be avoided, especially when original or planted forest belts to break the force of the wind cannot be maintained.

Draining.—Cacao is invariably cultivated in conjunction with trees of some kind or other, and an ordinary plantation is usually a good example of a mixed forest vegetation. It is erroneous to suppose that such land does not require draining; it is as necessary for the cacao plant and its arborescent associates as for any other product, in order to encourage the free circulation of air, water, and food materials throughout the soil, to check wash on steep hillsides, and to form effective outlet channels for excessive water during wet monsoons or floods. Nevertheless, on many cacao estates in Ceylon draining appears to be neglected to a remarkable degree, as the covering to the soil by the fallen leaves and protection against exposure and wash by the overhanging foliage seem to mitigate the evil results which usually accompany the exposure of soils when occupied by other products. The cacao grows luxuriantly in spite of the undrained and sour condition of the soil.

On hillsides the drains need be only about one-and-a-half to two feet deep and about 18 inches wide. They should be made almost at right angles to the slope in order to check the formation of gorges and on a small incline of, say, 1 in 20 feet; if possible they should open into natural ravines. The distance of the drains from one another will vary according to the slope and climatic conditions; on flat land a distance of 60 to 70 feet seems sufficient, whereas on steep hillsides 20 to 30 feet is not too close. The drains should be systematically cleared prior to the heavy rains.

Cacao trees when once established appear to be able to stand occasional floods. Several acres of mature cacao at Peradeniya are subject to floods once or twice each year; the water rises to a height of three or more feet above the bases of the trees, and remains in a somewhat similar condition for a few days; nevertheless, these plots yield fairly good harvests of two to three hundred pounds of cacao per acre, per annum. In the Amazon valley cacao trees often grow wild in districts which are periodically flooded, and the cacao trees, it is said, have their stems under water for as long as three

months at a time. The same occurs on some plantations for periods of a few days on healthy cacao in Venezuela and in several parts of Ceylon. An occasional flood, lasting only a few days, does not kill the trees, but where the stems are under water for months considerable damage is undoubtedly done.

Roads.—Roads are essential on cacao estates to prevent damage to the cacao trees, to facilitate the transference of crop and manure, and to assist in plant sanitation and other operations.

Clearing Operations.

In the cacao districts of Ceylon it is customary to fell all the large and small trees and to burn these with all the weeds on the new clearing. The burning of the debris is often accompanied by a partial sterilisation of the soil, a change which, though it prevents the rapid growth of the weeds, is detrimental to the soil. In very dry parts of Ceylon, where cacao is being tried experimentally, it is considered advisable to allow a few of the larger trees to remain in order that the ground may be properly shaded from the commencement. The retention of a few trees along the borders of estates is considered important when the winds are very strong; the existence of trees in definite belts might appreciably check the spread of diseases from one area to another. Most planters prefer to plant their wind or disease belts rather than allow original forest trees to serve such purposes; with cacao this is a comparatively easy matter, several leguminous trees being known which are suitable for cacao.

Nurseries and Shading.

Nurseries.—Seeds germinate in a few days if regularly watered. If it is intended to plant stumps in the following year a well-prepared nursery should be used. The larger the plant in an interval of 5 to 6 months the better. Good growth has been obtained by adding cattle manure and leaf-mould to the nursery soil before using. The use of seed baskets or bamboos is to be recommended as there is minimum interruption in the root development during planting operations; the non-success with which cacao stumps are used has led to the increased use of baskets in most districts. Considering that so few trees are planted per acre, and that baskets are so cheap, the disuse of the latter at the expense of the interruption in development of the cacao plant is not to be recommended.

Seedlings taken from a nursery are difficult to rear as the tap roots or lateral roots invariably get damaged, even when a transplanter is used. Unlike tea, rubber, and many other products, the seedlings of cacao will not stand much destruction of the root system, and if neither baskets nor bamboos are available, the use of seed at stake is in most cases preferable to the transplanting of seedlings in countries which are subject to periods of drought similar to those in this island.

According to information given in the Official Gazette, Demerara, 1905, "the seeds should be sown in well-drained and raised beds of good loose soil mixed with leaf-mould or coconut fibre, at distances of about 6 inches apart, and one inch below the surface of the soil. The beds should be protected from the sun and regularly watered in dry weather. When the young plants are between 10 and 12 inches high they will be ready to plant out."

The seeds should not be sown fresh from the fruits with all the viscous pulp adhering to the integuments, as the latter is liable to induce fermentation and produce a bad effect on the germinating embryo. The seeds should be partially dried by exposure to the sun or by rolling them in dry earth; they will thereby lose a large proportion of superficial pulp and water and germinate more rapidly when sown. If holing and refilling have been completed, the seeds, basket or bamboo seedlings should be planted as soon as possible. Planting operations should be carried out only when rain is certain, and shading adopted according to requirements.

Shading.—Even when basket plants are used, it is customary, in Ceylon, to shade the young specimens by means of twigs bearing foliage or by the fronds of wild ferns. When seedlings from the nursery are used, shading is imperative in districts liable to suffer from drought.

In Samoa, the papaw tree, and in the West Indies the banana plant, are used to give the first shade to the young cacao plants; these are cut down after a few years when the permanent shade-trees have established themselves.

In Central America the cassava or manioc is often used; in Madagascar the tobacco chestnut has been recommended for the purpose of shading young cacao plantations.

The cacao plants in Surinam are shaded much in the same way as in other western tropical cacao areas; the young plants are first shaded with living specimens of Musa species and also cassava, *(Manihot utillisima)* both of which are indirectly used as catch crops; these temporary shade plants are finally replaced with trees of *Erythrina umbrosa* and *E. glauca*, preference being given to these on account of the light shade they give and the protection against wind which they afford. If trees giving a very dense shade are used the cacao plants produce long and weak branches; if the shade trees are only allowed to occupy the land for a limited period and regularly resupplied this does not occur, and the soil is considerably improved.

Distance and Holing.

Distance.—It is a principle recognised in forestry that closely-planted trees tend to produce long slender stems, and widely-planted ones shorter stems with a better and lower branch system. The production of tall cacao trees is a great disadvantage because

the upper parts cannot be as easily inspected in plant sanitation work, and the picking of the crop is accomplished with difficulty and increased expense. Well-developed cacao trees often attain a height of twenty-five feet and a lateral spread of branches and foliage measuring twenty feet or more in diameter. The following measurements may be interesting as showing the dimensions of the vegetative parts of a few cacao trees of known age, grown at the Experiment Station, Peradeniya. (One foot equal to 30·48 cm.):—

Variety.	Age.	Height of tree.	Diameter of foliage and branches.
Amelonado ...	3 years	8 to 11 feet	4 to 10 feet
Amelonado ...	10 ,,	15 ,,	18 ,,
Forastero ...	3 ,,	8 ,,	9 ,,
Forastero ...	10 ,,	15 to 25 ,,	18 to 20 ,,
Caracas ...	3 ,,	8 ,,	6 ,,
Caracas ...	10 ,,	14 ,,	10 ,,
Nicaraguan ...	3 ,,	6 ,,	5 to 6 ,,
Nicaraguan ...	10 ,,	15 ,,	14 ,,

The above rates of growth are obtainable when the cacao is interplanted with shade trees of Erythrina lithosperma. In Ceylon, Cameroon, Samoa, and the West Indies, etc., the cacao trees are planted at distances varying from 6 to 25 feet apart, according to the age and variety of the trees. The cacao plants in Trinidad are planted at distances varying from ten to sixteen feet apart, and between every two plants there is usually a shade tree; in Grenada a distance of nine feet apart is very frequently adopted for cacao plants. In Ceylon, when an estate is being planted with cacao only, a distance of about ten feet apart is usually originally adopted for the Caracas or Nicaraguan types and about twelve to fifteen feet for the Amelonado and Forastero varieties. There is no doubt that such distances, even when the estate is interplanted with shade or wind-belt trees, allow sufficient freedom to root and foliar developments until the trees are in bearing; subsequently, however, the trees must be thinned-out, and a distance of fifteen to twenty feet for Caracas, and fifteen to twenty-five feet for the larger Forastero types is commendable for trees after their twelfth year. When inter- or catch-crops are systematically cultivated the maximum distance for the cacao plant is usually allowed.

In the cultivation of cacao, I am inclined to recommend moderate close-planting at the beginning and thinning-out gradually after the trees have begun to bear crops; cacao trees left after thinning-out has been adopted gradually take up the available soil, and their branches spread to form a good shade; the remaining trees do not appear to suffer very much from the effect of decaying stumps. Such a course minimises the wash and exposure to the soil so detrimental in the tropics in the early life of a cacao plantation, and is preferable from a financial standpoint as it always

allows one to gather the small or first crops from a larger number of trees. The observations made at the Experiment Station, Peradeniya, support this recommendation, though I am fully aware of the very opposite being advised by some authorities.

In countries where cacao is grown at various altitudes the trees at the higher elevation are rarely so well developed as those in more suitable climes; similarly the growth on cabooky or gravelly soils is less pronounced than on rich alluvial flats. It is obvious that the trees, which, either in virtue of the climate or soil, cannot develop a vegetative system as large as those growing under more favourable conditions, will not take possession or protect as wide an area of land, and can therefore be planted closer together. In most cacao-growing countries ten to twelve feet is considered to be near the minimum distance and fifteen feet the most usual distance for planting cacao.

In all countries the planter must make his own calculations as to the distance at which the cacao must be planted, as so much depends upon the variety selected, method of cultivation, soil, and climate. The distance adopted should be one which will allow free development of all parts of the plant, at different ages, free access to all parts of the soil and trees for simplification during picking and manuring operations, and be such as to allow one, either by spraying, excising or trenching, to successfully operate against diseases when they arise.

Preuss, as the result of his investigations in many cacao-growing countries, recommends a distance of 4 by 4 to 5 by 5 metres as the best for permanent cacao, and that shade trees should be selected from the Leguminosæ and planted 12 by 12 to 15 by 15 metres in cacao districts with relatively dry climates, and 20 by 20 metres where the climate is damp and no dry season occurs. Cacao trees grown without shade often mature earlier and die sooner than those planted with shade.

Holing.—It is usually necessary, in order to obtain a soil with plenty of available food and to provide for the free and rapid development of the roots of the young plant, that holing should be done. The holes are generally made 1½ to 2 feet in diameter and 1½ feet in depth; the earth is heaped up near the hole and exposed to the atmospheric agencies for one or more months, and about one week prior to planting the hole is refilled in order that the usual shrinking may occur before the seedlings are planted. The larger the holes, the better for the trees as the plants will get a better start; the dibbling in of seeds in small holes made by sticks is not to be recommended. In Surinam, holing is not, according to Preuss, very efficiently carried out. In Samoa, where the soils are often very loose, holes are recommended two feet deep.

Wind-Belts and Shade Trees for Cacao.

The necessity for either of these, the preference for shade as against wind-belt trees or vice versa, and the best distance at which to plant them, have long been discussed by cacao planters.

Wind-Belts.

The effect of wind has been studied at Peradeniya, on several plots from which the timber and shade trees have been entirely removed. The effect of strong winds, particularly during the months of January and February, is to produce partial or complete defoliation of the cacao trees. The leaves become brittle and dry and finally drop, and within a couple of weeks the greater portion of the shoots on the upper parts of the stems and branches are leafless; some of the shoots burst into new leaf at a later date, but others appear to die in consequence of the hot dry wind constantly playing over them. The twigs were simply dried; those under observation bore no signs of fungus or Helopeltis.

On particular areas, much exposed to the wind, the cacao trees are defoliated twice in the year, viz., February and September; such behaviour must result in the reduction or exhaustion of reserve store materials within the plant, since the assimilatory organs are repeatedly destroyed, and new leaf is manufactured at the expense of reserve material. The cacao tree cannot stand such frequent defoliation and exhaustion, and the effects will be seen on the general health of the trees and their crop returns. Cacao trees under proper cultivation do not drop all their old leaves yearly, but up to a certain age appear to show a nett increase year by year. There is, furthermore, the possibility of a too extensive destruction of floral organs, the strong winds readily detaching the exposed delicate flowers, no matter whether they possess a fertile or nonfertile pistil. The bad effect of strong wind on the crop of cacao has been conclusively proved at Peradeniya as is obvious from the table given below:—

Yield of Cacao.

Year.	Without wind-belt trees.	With wind-belt trees.
1903	1,275 fruits per acre ...	2,463 fruits per acre.
1904	2,942 ,, ,, ,, ...	5,268 ,, ,, ,,
1905	4,023 ,, ,, ,, ...	6,430 ,, ,, ,,

Exposure to strong wind is detrimental to cacao. The protection afforded by trees, supposed to be used for shade purposes only, is undoubtedly in part attributable to the way in which they break the force of the wind: shade trees of the *Erythrina*, *Albizzia*, or rubber tree types protect the cacao from wind, and

though they are not the most effective species for this purpose, cacao grows exceedingly well, in windy places, when provided with only these arborescent associates.

Shade and Wind-Belt Trees.

The species of trees which can be used as wind-belts or shade trees are very numerous, and among the more notable ones may be mentioned the following:—

Adenanthera pavonina, *Albizzia moluccana*, *A. Lebbek*, *A. odoratissima*, *A. stipulata*, *Erythrina lithosperma*, *E. umbrosa*, *E. Indica*, *E. ovalifolia*, *E. velutina*, *Artocarpus integrifolia*, *A. nobilis*, *Cassia Siamea*, *Casuarina equisetifolia*, *Eugenia Jambos (Jambo)*, *Filicium decipiens*, *Melia dubia*, *Mesua ferrea*, *Pithecolobium Saman*, *Castilloa elastica*, *Manihot Glaziovii*, *Hevea brasiliensis*, *Gliricidia maculata*, *Pterocarpus indicus*, *P. marsupium*, *Vateria acuminata*, *Acacia pycnantha*, *Cedrela serrata*, *C. Toona*, *Eucalyptus Leucoxylon*, *E. marginata*, *Grevillea robusta*, *Michelia Champaca*, *Myristica laurifolia*, *Azadirachta indica*, *Peltophorum ferrugineum*, *Swietenia macrophylla*, *Tamarindus indica*, *Thespesia populnea*, and others.

Local climatic conditions will determine which are the best species to cultivate and the distances and methods to be adopted.

Shade Trees for Cacao.

The much disputed question as to the necessity of shade trees for cacao has received a considerable amount of attention during recent times, and the results of physiological research and experiments have supplied valuable information on this subject. The function of shade trees for cacao varies not only in the countries where the plants are cultivated, but in districts in the same island; and also with the seasons of the year, method of treatment to which they are subjected, characteristics of the species selected, and the distance they are planted apart.

The cacao tree is not what might be termed a robust type of plant either in its vegetative or sexual parts, and compared with those which yield Para rubber, tea, coconuts, and even cinchona, proves to be relatively weak when exposed to severe conditions of air or soil. The leaves are, when young, easily torn by strong winds, and the tender flowers readily detached by heavy rains and wind in boisterous seasons. In nature, the cacao tree forms part of the lower strata of forest vegetation, and is usually more or less shaded by the larger arborescent forms found in such areas; it is commonly believed to be a shade-loving plant, hence the supplying of abundant shade trees wherever it is adopted for cultivation. Many persons of considerable experience in the tropics have not hesitated to state that cacao thrives better or as well when grown alone without any shade trees whatever, and have even gone so far as to assert that cacao requires constant strong light in order that the leaves may perform their proper functions, the flowers be effectively pollinated, and diseases be kept in check. Constant

strong light, even in Europe where it is never very intense, is, in the opinion of many who have worked at the subject of stimuli and foliage, not essential: intermittent light has, in many cases, been proved to be as effective as continuous light, and the shading of foliage, within certain limits, instead of being accompanied by signs of interference of foliar functions, has been shown to be beneficial. In most parts of the tropics, and especially those liable to alternately wet and dry periods, a moderate amount of shade, either temporary or permanent, has been proved to be advantageous for the cultivated plants in such areas.

Shade Trees in Ceylon.

Experience in Ceylon has been such as to convince many persons that the interplanting of cacao with other species is beneficial when properly carried out, and, in some cases, in addition to leading to an improvement in the cacao, has furnished other products of considerable commercial value. From considerations regarding the chemical changes in the soil, plant sanitation, and the requirements of the cacao tree, shade trees may be successfully cultivated in most parts of Ceylon and in other tropical countries having similar climates. Modifications in methods of treatment are necessary according to the species of shade trees cultivated and the climatic forces prevailing, though the principles are, in most cases, approximately the same.

In Ceylon, trees of *Erythrina lithosperma*, *E. indica*, *E. velutina*, *E. umbrosa*, *E. ovalifolia*, *Albizzia moluccana*, *A. Stipulata*, *Pithecolobium Saman*, *Gliricidia maculata*, *Hevea brasiliensis*, *Castilloa elastica*, *Manihot Glaziovii*, *Artocarpus integrifolia*, *Michelia Champaca*, *Melia dubia*, *Mangifera indica*, *Bombax malabaricum*, *Sterculia fœtida*, *Cassia Siamea*, and others are commonly met with on cacao estates; occasionally palms such as *Areca Catechu*, *Cocos nucifera*, *Elæis guineensis* are allowed to grow and shade the cacao. It is obvious that nearly all the plants here enumerated are of use not only as shade but for other economic purposes, and their interplanting with cacao can be more appropriately discussed when dealing with mixed products. The real shade trees consist, in Ceylon, mainly of species of *Albizzia*, *Erythrina*, *Hevea brasiliensis*, *Castilloa elastica and Manihot Glaziovii*.

Cacao Shade in Africa.

Erythrina species are largely used for permanent shade in most cacao countries, and Preuss is of the opinion that those species which become leafless in the dry season are not harmful but very serviceable in a moist climate such as exists in Cameroon: they are, however, less suited for such dry countries as Trinidad, and he suggests that in dry hot districts evergreen and not deciduous trees should be used for shade. In the Cameroons the cacao planters see the necessity of permanent shade for the cacao, but up to now no very definite selection appears to have been effected.

Photo by H. F. Macmillan.

CACAO UNDER ERYTHRINA SHADE.

ERYTHRINA TREES AFTER BEING PRUNED.

M Rousselet, Manager of the cacao plantations of Lower Ogoone (French Congo), recommends the planting of *Musanga Smithii*, known as the "Combo-Combo" by the natives; it gives an intense shade and grows rapidly, but will not stand transplantation, and can only be reproduced from seeds.

Cacao Shade Trees in Madagascar.

Regarding cacao cultivation in Madagascar, Deslandes* dwells on the necessity of gradually accustoming the young nursery cacao plants to the light on the plantation, and is emphatically in favour of shade on mature cacao estates. He believes that young cacao trees cannot grow well when fully exposed to the sun, and shade trees must be used, though as the tree grows older the latter can be gradually reduced. This is effected by having a shade composed of two species of plants (1) the banana to furnish temporary shade for the first few years, and (2) *Albizzia Lebbek* planted at the same time as the banana, but to be kept as a permanent shade after the removal of the latter. The bananas should be planted 18 months before the cacao.

Albizzia Lebbek is, according to Deslandes, employed in the East to the exclusion of all other trees; this, however, cannot apply to Ceylon. Deslandes suggests that other species may be used with advantage, and mentions *Albizzia moluccana* and *A. stipulata*, *Pithecolobium Saman*, *Erythrina* species, etc., though preference seems to be given to *Albizzia Lebbek* as a permanent shade on account of the successful growth obtained with this species at the Station de l'Ivoloina. At this Station the trees of *A. Lebbek* are pruned in order that the branch system may be made to offer suitable shade for the cacao trees. It has been pointed out elsewhere that this species is, in Ceylon, deciduous and every year passes through a leafless state during the hot dry season and is not as good, for shade purposes, as *A. moluccana* or *Erythrina lithosperma* when the latter are systematically cultivated.

Lacharme has advocated the use of the wild tobacco tree as a shade for cacao on account of its rapid growth; the same authority recommended the use of *Erythrina umbrosa*.

Shade Trees in Central America.

The cacao plantations are often shaded with a large variety of trees, wild Castilloa rubber and various fruit trees being commonly met with. In parts of Nicaragua where the annual rainfall is under 1800 mm., the surrounding vegetation and even the cacao trees have a dwarfed, low-branching habit; the dry season extends from November to May, and in consequence of this the shade for the cacao trees is of great importance. The cacao and shade trees are always kept low, and there are often as many shade trees as cacao plants on good estates. Preuss states

* Les Abris du Cacaoyer, L'Agriculture Pratique des Pays Chauds; No. 15, Nov.-Dec., 1903.

that among the more common shade trees he saw were *Gliricidia sepium* (Jacq.) Sted., a *Jatropha* species growing to a height of about four metres, *Cæsalpinia exostemma, D. C.*, and *Erythrina* species. Trees of *Theobroma bicolor* are also sometimes used as shade for the cacao trees. In Venezuela and the Antilles the mahogany of the country (*Cedrela sp.*) is used as permanent shade for cacao.

Cacao Shade in Java.

Gillivray* states that on one cacao plantation where the *Castilloa* rubber trees are ten years old and planted among seven-year-old cacao trees, both are doing well; he suggests that the *Castilloa* trees should be planted about 36 feet apart when grown in conjunction with cacao. Gillivray recommends that *Erythrina* trees and *Manihot* be grown as temporary shade plants; *Cæsalpinia dasyrrhachis*, Kurz, is advised as a permanent shade because in Java during the dry season it retains its foliage.

In Java, according to Van Krieken, the *Albizzia stipulata* has been recommended instead of the *Albizzia moluccana* and the *Albizzia Lebbek* or "black-wood," on account of its timber which is insect-proof and more valuable for building purposes.

Wind-Belts and Shade Trees in Samoa.

In Samoa, shade trees are specially required along the coast lands where a drought extending from four to six months may annually occur, and, according to one authority,† are advisable at higher altitudes or wherever the cacao is grown in exposed situations. In Samoa it has been recommended that strips of the original forest, measuring forty-five feet in width, or these together with lines of rubber trees (*Hevea brasiliensis and Castilloa elastica*) should be left to break the force of strong winds, and individual forest trees be left on the cacao plantation to serve for shade.

The introduced trees—*Albizzia stipulata* and *A. moluccana*—are recommended to be planted at wide distances—10 to 20 trees per acre—these to remain as the permanent shade and their branches to be occasionally lopped. The papaw tree is recommended as the first shade tree for a cacao estate, and in Samoa would appear to occupy a position comparable with that of the banana in the West Indies.

Cacao Shade Trees in Guam.

W. Safford,‡ in his remarks on the cacao in the island of Guam, states that permanent shade trees are not necessary, and he appears to consider the retention or planting of wind-break trees of much

* Castilloa als Kakao-Schattenbaum in Java, Der Tropenpflanzer, Vol. VI., p. 146, 1902.

† Bulletin of the Imperial Institute, London, March, 1904.

‡ Useful plants of Guam, by W. E. Safford.

more importance. The young cacao plants are sheltered by rows of bananas planted at more or less regular distances; in addition to these the planters, when clearing for cacao, allow belts of trees to remain and occasionally plant hedges of *Cæsalpinia Sappan* to act as wind-belts.

Trees of *Erythrina indica* and *Artocarpus* are planted to shade the cacao in exposed places.

Cacao Shade Trees in Trinidad.

Hart states that on flat land in Trinidad the general practice is to use shade trees, and points out that in the lower-lying lands of Trinidad the tree generally used is the "Bocare" or *Erythrina velutina*, but that in the higher lands the "Anauca" or *Erythrina umbrosa* is preferred, both being known, together with several other *Erythrinas*, as "Bois Immortel." He also seems to favour *Pithecolobium Saman* in preference to the "Immortel" for use as shade in certain districts. The *Erythrinas* are planted at distances varying from 35 to 50 feet and *Pithecolobium Saman* as much as 50 to 60 feet apart. In Trinidad smaller shade plants are used such as Indian Corn (*Zea mays*), Pigeon Pea (*Cajanus indicus*), Tannias, Eddoes, or Cocoes (*Colocasia esculenta*), Castor oil (*Ricinus communis*), Cassava (*Manihot utilissima*) and the Banana or Plantain (*Musa sapientum*). According to Hart, the "Banana or Plantain used for shade is usually planted intermediate between the permanent rows of cacao. If cacao is at 15 feet, then banana 7½ and so on. A variety of Plantain commonly known as the "Moko," or "Jumbi plantain," is preferred to other members of the family by Trinidad planters for the purpose of affording secondary shade. This plant proves to be very suitable for shade purposes in the intermediate stages." This plantain is described by Preuss as intermediate between the "sweet" banana and "bread" banana.

Opinions Regarding Shade Trees in the West Indies and America.

Opinion seems divided in the West Indies as to the necessity for shade trees, though most persons agree that beneficial results accrue by cultivating such trees in association with cacao. According to one authority*, in Grenada they do not use any shade, but in Trinidad shade is used on almost every estate, but whether the trees or the soil require such protection, and how much the improvement is due to the fall of the flowers rich in nitrogen, or to the leaves, or to the action of the roots and their bacterial nodules, does not appear quite clear. Freitas contends that in Grenada the cacao was once as thickly shaded as in Trinidad, but after a time the shade trees were removed and now hardly an estate finds it necessary to use shade trees. In some parts of Jamaica cacao is successfully cultivated without shade, but in others

* Jamaica Bulletin, September, 1905.

it is required. In Dominica, according to Nicholls, the shade tree—*Erythrina umbrosa*—is not looked upon with favour, and most estates do better without than with shade. Carmody considers that, in Trinidad, the value of shade trees depends upon local conditions. Hall contends that in Surinam shade trees can be discarded in irrigable districts, but that other estates which have attempted to grow cacao without shade suffer considerably in the dry season.

According to the Agricultural News*, the "Madera" shade tree of Nicaragua (*Gliricidia maculata*) is regularly frequented by a large number of humming birds, and is perhaps worth cultivating for these alone. This species belongs to the natural order Leguminosæ, and young cacao trees are thriving in the Botanic Gardens, Peradeniya, under it. Hart† states that this is the tree in general use as a shade for cacao in Nicaragua: the "Madera" is planted from seeds in lines about 13 feet apart. After allowing the shade to grow for eighteen months or two years, the cacao trees are planted in the same lines as the shade trees and alternating with them in the rows; the "Madera" becomes the permanent shade of the plantation. Judging from the specimens growing at Peradeniya this species does not appear to be characterised by a quick rate of growth or the production of a large branch system bearing abundance of foliage, and is decidedly inferior to the species already used in Ceylon for shading cacao, though according to Hart‡ it is being tried by planters in Trinidad.

A recent§ publication has the following remarks on shade trees in the West Indies:—"Most of the Delegates to the Trinidad Agricultural Conference were struck by the way Trinidad Cacao plantations were densely shaded by tall-growing Immortel trees (*Erythrina velutina* and *E. umbrosa*). It may safely be assumed that where a practice is so universally followed in so large and intelligent a planting community, it has been evolved by experience, and is well suited to the local conditions. Yet it is conceded by Trinidad planters that, while they see the necessity of regulating and controlling shade, the trees in question are so large and tall as to be incapable of practical every-day pruning and thinning. In St. Lucia, although these two varieties of Immortel have been tried, they have in nearly every case been discarded in favour of the smaller shade Immortel (*Erythrina indica*) which it is possible to keep entirely under control, and when the shade becomes excessive the oldest trees may be destroyed without material damage to the cacao trees. I still think it is the most suitable shade or rather shelter for cacao. I say shelter, believing that the Immortels and the other cacao shade trees are more useful as wind protectors than as interceptors of solar rays."

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* Agricultural News, Barbadoes, Vol. III., No. 53, 1904.

† Bulletin of Miscellaneous Information, Trinidad, September, 1903.

‡ Annual Report, Botanic Garden, Trinidad, 1903.

§ Annual Report, Botanic Station, St. Lucia. 1904-05.

Hudson, in his 1905-06 Report for St. Lucia, gives his views on this subject after a visit to the principal cacao estates in Trinidad and Grenada, the estates in the former island being noted for their heavy and those in the latter for their light shade. Hudson concludes that the shade in Trinidad, though necessary to a certain degree, is too intense, and that better results would be attained by adopting shade trees such as *Erythrina indica*, which are more easily controlled. He points out that much of the success on Grenada plantations, where no shade at all is used, is due to the fact that the cacao plants are planted very close, often nine feet apart, and thereby made to offer mutual protection against wind and sun; nevertheless, he believes that in exposed places wind shelter is always, and shade trees are sometimes, necessary in order to produce healthy cacao trees. He recommends *Hevea brasiliensis* and *Erythrina indica*, protected by wind-belts of *Inga Vera*, for these purposes.

Albizzia.

Albizzia is the name of a genus of the natural order Leguminosæ, and is usually represented in most cacao-growing countries. In Ceylon the four most notable species are, *A. Lebbek*, Benth., *A. stipulata*, Boir., *A. odoratissima*, Benth., and *A. moluccana*, Miq. The first three are indigenous in Ceylon, India, and Malaya, and the last-named is an introduced species from Moluccas and Java.

A. odoratissima, *A. Lebbek*, and *A. stipulata* agree in that they will grow in cacao-growing districts in Ceylon, in being all slow growers, and in being partially or completely leafless during particular periods in the year. *A. stipulata**, the most common of the three, becomes leafless during December-January, and remains in that state for periods varying from 9 to 21 days each year. The introduced *Albizzia moluccana* differs from the other three in that it has a very rapid rate of growth and is an evergreen tree.

Albizzia moluccana, Miq.

The very large demand for seeds of this tree is sufficient evidence of the extent to which it is used in Ceylon, and a few words on the subject may be appropriate. It is an evergreen tree, native in Java and Moluccas, and was introduced into the Peradeniya Gardens about 1880. It is without doubt one of the quickest-growing trees in the tropical world, and the dimensions attained often exceed those of our largest trees of *Bombax malabaricum*. Within ten to thirteen years the tree may attain a circumference of 10 feet and a height of 60 to 80 feet, with a branch system extending over 40 feet on all sides. Self-sown seeds germinate rapidly, stumps of trees often give off quick-growing leaders, and trees which have been "bark-rung" continue to live for three to four months after treatment.

* Foliar Periodicity of Endemic and Indigenous trees in Ceylon, Annals of Botany, Peradeniya, Vol. II., Part III., 1905.

It has been extensively planted in cacao for purposes of shade, nitrogen collecting, and opening the soil. Each of these functions it certainly fulfils, but there is a possibility of ruining cacao cultivation if the trees are planted closer than 60 to 80 feet apart and are allowed to grow uninterruptedly. *Albizzia moluccana* in its young stage—up to five or seven years—appears to be a suitable shade, and may be compared in this respect with good-sized trees of *Erythrina* species (Dadap and Bois immortelle); in later years, however, the dimensions attained are such as to prevent the light from reaching the cacao trees, and the fungus grows most luxuriantly. The abundance of the woody tissues formed and the evergreen nature of the tree necessarily lead to an exhaustion of the surrounding soil, and even when the tree is felled the root-nodules are never in such abundance as to enrich the soil in nitrogen to a very considerable extent.

The abundance of trees of this species has often been one of the main causes leading to a bad state of disease in Ceylon and, in such cases, the felling and removal of such colossal trunks and branches further threaten to well-nigh extinguish all cacao trees in local areas. It may be classed as a more dangerous shade for cacao than the common *Erythrina* species, and is, by some persons, regarded as an inferior nitrogen collector. On the other hand, *Albizzia moluccana* is decidedly superior to any species of *Erythrina* as a soil opener, and on this account may be very useful when planted among cacao. The timber is eminently suited for making tea boxes, boats, light packing boxes, picture framework, &c.

But the disadvantages accompanying the uninterrupted growth of trees of this species can be readily overcome by lopping the branches every year, and bark-ringing and re-supplying every five or seven years. Elsewhere it has been shown that the weight of organic matter obtainable by the systematic pruning of this tree is considerable, and its successful cultivation depends mainly upon such treatment being adopted,

The uninterrupted trees of this species possess, when three years old, a main stem 50 feet high and a lateral branch system measuring 25 feet in diameter. If the production of tall woody tissue is prevented by removal of the terminal bud when the tree is in its first or second year, the lateral branches become much better developed and more effective as a shade for cacao, though they then appear to be more easily damaged by strong winds. The frequent lopping allows the light to intermittently affect the leaves of the cacao tree, and the ringing and re-supplying prevent or check exhaustion of the soil in the neighbourhood of cacao trees. If the *Albizzia* trees are treated as advised they can be planted 20 to 30 feet apart in ordinary cacao; they cannot be propagated from cuttings, but are easily reared from seed basket plants and less easily from stumps.

Erythrina.

This is, like *Albizzia*, a genus of the natural order Leguminosæ, and representatives are well distributed through most parts of the tropical zone. *Erythrina umbrosa* is a species which in the beginning of the cacao industry in Ceylon was extensively used on account of its reputed usefulness on West Indian cacao estates. It is a native of tropical America, and in good soil may produce a thorny stem over forty feet in height, but the lateral spread of the branches bearing foliage is comparatively poor.

The large thorns are sometimes troublesome to coolies' feet, and for this reason together with the poor shade the foliar system gives, this species is falling into disuse in Ceylon. The scanty foliage may, however, under certain conditions be advantageous in places which require sunshine for the eradication of diseases or where light is not sufficiently abundant or intense.

Erythrina indica, *E. ovalifolia* and *E. velutina* are not commonly used on cacao estates in Ceylon; the first-named annually passes through a leafless phase of 21 to 36 days' duration, in the dry hot season.

Erythrina lithosperma has, in Ceylon, been proved to be very suitable as a shade for cacao on account of its rapid rate of growth and power of producing large quantities of foliage, the manner in which it withstands frequent lopping, its easy propagation from cuttings or seeds, and its thornless bark. This species may be successfully propagated by means of seeds, stumps or cuttings; the growth is rapid in all cases, especially when cuttings are used. Cuttings are taken, about two inches in diameter and five feet in length, and planted in holes one foot deep; if this is done in wet weather there is a good spread of foliage in six months, and in two years flowers and seeds are produced, and the trees may have grown to a height of twenty feet. The trees can be regularly lopped during the wet dull weather and allowed to produce and retain their foliage right through the hot dry season. On a clearing, every cacao plant can be separated by a cutting so that the number of trees of each kind is approximately the same. When a few years old they can be bark-rung and re-supplied in a more effective manner than is possible with *Albizzia*, and are perhaps to be preferred to the latter on account of their adaptability to pollarding on cacao estates, and the large amount of organic matter obtainable thereby. An established cacao plantation can be interplanted with trees of *Erythrina lithosperma* at distances varying from 15 to 30 feet according to the frequency of lopping and re-supplying adopted.

Trees of *Pithecolobium Saman*, *Gliricidia maculata*, *Melia dubia*, and others can be treated in a somewhat similar manner, but are, in Ceylon, less adaptable and less efficient for shade and other purposes than species of *Erythrina* and *Albizzia*.

The treatment of shade trees as previously described is only possible when the trees selected are not required for other purposes, and it is obvious that similar operations on trees of *Mangifera indica* or *Hevea brasiliensis* when grown for additional purposes are beyond the range of financial economy. Before dismissing the species of *Erythrina* and *Albizzia* it is advisable to lay stress on the principles advocated. A tree cannot be grown in association with cacao for shade purposes without affecting other conditions vital to the product under cultivation, and one has to seek a method which will combine the good effects of shade with those of the other forces at work.

The cacao tree requires more or less continuous shade during its vegetative or early life, but once the plantation is in bearing and the branches of adjacent trees begin to overlap and constitute a self-shade the conditions and requirements are modified. Experiments have shown that, in Ceylon, good results are obtained when the shade is regulated in such a manner that light is not allowed to play on the cacao to its maximum variation; if the branches of the shade trees are lopped at the beginning of the dull rainy weather and allowed to retain their foliage during the hot dry season, the play of the sunshine on the cacao is controlled so as to be relatively constant throughout a year of varying seasons; the cacao receives additional light in the dull weather when the periods of maximum flower production and setting of fruits occur, and is well-shaded by the abundant foliage during the hot dry days from January to March and April. Furthermore, the frequent lopping and the regular killing of trees allow the light to penetrate to all sides of the cacao tree at some part of its career, and the return of large quantities of leaves to the soil provides the latter with good materials of use to the plant, and forms a thick layer which persists at the surface and checks evaporation until the hot dry days are over. In this system of cultivation it is intended that the only trees which shall be permanent are those of cacao; all the others play one or more roles in its development, and under such conditions good results have been obtained.

Rubber Trees for Shade.

It is obvious that rubber trees cannot be lopped and bark-rung in the manner recommended for trees of *Erythrina* and *Albizzia*, and their value for shade purposes can only be considered as of minor importance.

Rubber-producing plants of arborescent types which can be grown in association with cacao are numerous; they include *Hevea brasiliensis Castilloa elastica*, *Manihot Glaziovii*, *Funtumia elastica*, *Ficus elastica*, and species of *Sapium*; gutta-percha trees such as *Payena Leerii*, *Palaquium Gutta*, *P. oblongifolium*, *P. petiolare* and others usually grow at too slow a rate to be considered as effective shade trees for cacao and may therefore be discarded.

Photo Lent by F. Holloway.

PARA RUBBER TREES SHADING CACAO

KEPITIGALLA ESTATE, MATALE.

Cacao Shade and Hevea Brasiliensis.

This tree owes its increased cultivation to the quality and quantity of rubber it yields rather than to its effectiveness as a shade tree. In fact, the three principal rubber trees commonly grown with cacao, in Ceylon, are deciduous, and do not therefore fulfil the essentials of an ideal shade tree, especially in those cases where the trees pass through a leafless phase extending through weeks and months of the hottest and driest part of the year.

It has been recently recommended by Hudson as a shade tree for cacao in St. Lucia, in preference to *Castilloa elastica*, on account of its being immune from the attacks of black blight and scale insect pests which also attack cacao leaves in parts of the West Indies.

The tree grows to an enormous size, especially in height, but the vertical growth can to some extent be checked and that of the lateral shading branches be induced by thumb-nail pruning the terminal buds, of the young trees. Thirty-year-old trees may have a height of 80 to 90 feet, and a circumference of 70 to 100 inches a yard from the ground.

The Para rubber tree is not evergreen. During the first two or three years the young tree may retain its leaves and show a nett increase in foliage at regular intervals. After the second or third year, however, the tree annually drops its leaves, but quickly puts on a fresh supply of young foliage. When growing under healthy conditions the trees in Ceylon and the Straits usually drop their leaves in February and March; in badly-drained places the foliar change is very irregular. The tapping operations are believed, by many persons, to change to a varying degree the periodicity of leaf-fall and production. In its native home the tree becomes leafless between March and July.

If it is intended to interplant cacao with Para rubber trees, the annual leaf-fall should be taken into consideration, as the leafless phase usually occurs when the dryness and temperature of the air are at the maximum, and the cacao plants will therefore be exposed to the dry hot winds at a time when rain is not expected. The annual fall of leaf provides a mulch of organic matter rich in potash, nitrogen, and lime; and though the leafless phase only lasts for a few days each year, the light is allowed to intermittently play on the cacao stems during a period when, in Ceylon, excision of diseased cortical tissues is carried on vigorously. The shortness of the duration of the leafless phase is in favour of this species for shade; observed trees remained leafless only for four to twenty-six days each year; the young leaves often appeared on some part of the tree before all the old ones had dropped.

The tree has a very well-developed root system, which may ultimately crowd out the cacao if planted too close. The tap root

may grow to a considerable length, and the lateral rootlets form a very compact mass. The lateral roots grow at varying rates according to the conditions prevailing, but if grown alone on moderately good and flat land, an incremental yearly increase in radius of about 10 to 12 inches or even more can be allowed for. In six to seven years the lateral roots of plants distanced 12 by 12 feet may be expected to meet; when planted 10 by 15 feet the larger distance will be more or less completely covered in 7 to 8 years. The rate of development of the lateral root system is of importance in connection with the relative distances for cacao and this shade tree, and is, by some authorities, said to be much quicker than that given above.

The cultivation of *Hevea brasiliensis* as a shade for cacao extends back to over fifteen years ago in Ceylon, the rubber being planted with the cacao in the belief that it would offer a shade comparable with that given by *Erythrina* trees, and also that it might ultimately prove to be of value as a source of rubber.

Cacao Shade and Castilloa Elastica.

This tree has been largely planted in Ceylon as a shade for cacao, and in many respects behaves similarly to *Hevea brasiliensis*. After the second year the trees are annually leafless for one day to nine days during the hot season—a period of leaflessness less prolonged than that characterising many species described elsewhere. All the rubber species used as cacao shade in Ceylon have the same disadvantage compared with Erythrina and Albizzia, viz., they pass through the leafless state when the heat and dryness of the air are at the maximum, and if it were not for the good cover of dry foliage on the soil at this period of the year the sudden exposure to intense light and heat might prove detrimental to the cacao.

The value of *Castilloa elastica* as a shade for cacao was discussed at the West Indian Agricultural Conference in 1901, and Morris* as far back as 1883 recommended that the tree might be grown for this purpose. This species has been successfully grown in parts of Java†, Tobago, and British Honduras in conjunction with cacao.

Quite recently, Hudson, in his 1905-06 Report for St. Lucia, West Indies, states that though this species gives good results when grown as a separate cultivation, he cannot recommend it to be grown as a shade for cacao, because it is liable to attacks of scale insects, mealy bugs, and black blight, which in turn attack the cacao trees beneath the *Castilloa*. According to Hudson, *Hevea brasiliensis*, when grown as a cacao shade, is at present immune from these pests.

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* Agricultural News, Barbadoes, May 10th, 1902.

† Der Tropenpflanzer, Gillivray, March, 1902.

Cacao Shade and Manihot Glaziovii.

As a shade for cacao during the greater part of the year this seems to be quite as suitable as any other form of rubber, owing to its low and profuse branch system; it has, however, the disadvantage that the leafless phase is prolonged right through the whole of the dry hot months, just when protection from exposure is required. The table given below will show the differences in the length of time and the period when the three rubber trees are leafless, and from these it is obvious that in order of merit as shade trees, *Castilloa elastica* and *Hevea brasiliensis* come first and *Manihot Glaziovii* last. It is a happy coincidence that the length of duration of the leafless phase is in somewhat the same ratio as the rubber-producing value of the three species, when grown in climates suitable for cacao.

Period and Length of the Leafless Phase.

Species.	Period of foliar change.	Number of days for leafless state.
Hevea brasiliensis ...	November to March ...	4 to 26 days.
Castilloa elastica ...	December to May ...	1 to 9 ,,
Manihot Glaziovii ...	January to April ...	4 to 76 ,,

Experience with Ceara rubber trees and cacao in Ceylon has not led to much increase in the planted area of this double cultivation; most planters in Ceylon prefer *Hevea brasiliensis*, whilst in some parts of tropical America and the West Indies preference seems to be given to *Castilloa elastica*, instead of *Manihot Glaziovii* as a shade tree and by-product for cacao.

Cacao Shade and Funtumia Rubber.

Funtumia elastica has been tried in Ceylon, and, on account of its rate of growth and the attacks of insects to which it is subject, is not looked upon with as much favour as *Hevea* or *Castilloa* rubber trees for association with cacao. In West Africa, Cameroon, and in the Congo Free State, *Funtumia* is largely cultivated and often with success as a shade for cacao. The *Funtumia* trees seed in their third or fourth year, and appear to grow equally well in lateritic or basaltic soils or those rich in humus. *Funtumia*, like cacao, can be best grown at low altitudes, an elevation below 800 metres, usually being considered favourable. According to Wildeman* it is one of the best shade trees for cacao, but as it is pyramidal in form it is unfortunately necessary to plant the trees close. The collecting of the latex is done in very much the same manner as in *Hevea*; the latex is said to flow freely and to be coagulated by adding water.

* E. de Wildeman, Revue des Cultures Coloniales.

Cacao Shade and Ficus Elastica.

Though *Ficus elastica*, the source of Gutta Rambong of commerce, grows throughout the cacao zone in Ceylon, it has rarely been associated with cacao, either for shade or other economic purposes. The trees grow to an enormous size and would afford too dense a shade for cacao except when planted at great distances; the distance at which trees of *F. elastica* would have to be planted would leave a very large part of the cacao without any shade, and for this reason alone is not likely to be used in preference to the rubber-producing species already mentioned. Nevertheless, there seems no reason why this species should not be used as a wind belt or part of a disease belt, in preference to many other species. *Ficus elastica* requires a rainfall of not less then 70 inches† per annum, and much care is required in order to successfully rear the young plants. The trees appear to thrive in the Peradeniya district until they are sixty or seventy years old.

These considerations lead us to the subject of the cultivation of cacao plants with various intercrops; the suitability of the various rubber-producing and other plants will now be discussed.

† The Cultivation of the *Ficus elastica* in India, by C. Bald.

CHAPTER VII.

CACAO AND OTHER PRODUCTS.

CACAO in its native home thrives among forest trees, and experience with this product when grown as a single crop or in association with other plants on large estates has convinced most cultivators that a mixed type of vegetation often gives the best results. The fact that in the cultivation of cacao only tree forms are dealt with, the individuals of which must be planted a fairly wide distance apart, and which even then do not bear fruits until they are several years old, necessitates, from a scientific and commercial standpoint, the consideration of the question of the interplanting and growing of other crops. These crops may be cultivated with a view to protecting the soil from exposure to heat and rain, or for purposes of manuring the cacao plants; or they may be grown to give a marketable produce at an early date—catch crops—or as permanent tree forms, such as fruit trees, rubber plants, etc. The mixed cultivation is usually recommended on scientific grounds, on account of the more or less permanent soil rotation effected and the check usually given to the rapid spreading of diseases. Many botanists assert that wherever cacao has been cultivated alone, the plants have rapidly deteriorated after giving good crops for only a few years, and apart from the advisability of distributing capital over more than one product, they concur in recommending that cacao be grown in association with other plants.

Inter and Catch Crops.

Where the cacao plants are closer than 10 feet the cultivation of inter or catch crops is limited to about four to eight years. Catch crops such as papaws, fibres, yams, cassava, bananas, coffee, chillies, groundnuts, citronella, lemon grass, pepper, gingelly, and perhaps tobacco and cotton, are among the most notable products for use under such conditions. If the intercrops are such that they can under ordinary circumstances be grown permanently, as rubber, tea, coconuts, and coffee, it is better to grow them only in widely-planted cacao, and to plant them among the cacao so that a fair root space is available for all the plants. Rubber, tea, camphor, coconuts, and coffee are among the products grown as permanent intercrops in cacao, and are being cultivated extensively in Samoa, Java, Ceylon, and the West Indies.

Catch Crops.

If real catch crops are grown to occupy the land from six to twelve months at a time, care should be taken not to plant them too near the cacao. A sufficient radial distance should be allowed for the growth of the roots of the cacao trees each year, and catch crops should not be planted within the cacao root area. In all cases the foliage or ashes obtained as by-products of the catch crops can be forked in around the trees or broadcasted over the areas which are partly occupied by the cacao roots. Among notable catch crops for export or use are lemon grass, citronella, cotton, cassava, and groundnuts.

Lemon Grass.—This gives a return six months after planting, and may be expected to yield about 14,000 lb., of fresh grass containing about 20 lb. of oil, per acre, per year, when grown on open free soil. The oil is valued at 4d. to 8d. per ounce, and is obtained by steaming the freshly-cut grass. A distilling apparatus is required, and can be kept in constant use by the grass from 300 acres. The fresh lemon grass contains 0.65 per cent. of potash, 0.09 per cent. of phosphoric acid, and 0.12 per cent. of nitrogen, but if the dried distilled grass is used as fuel and the ashes for manuring the cacao plants, the exhaustion is considerably reduced. The plant is propagated from slips or cuttings. It is being cultivated in parts of Ceylon, India, West Indies, and the Straits.

Citronella.—Citronella can be cultivated and distilled in exactly the same manner as lemon grass, and may be expected to yield about 50 to 60 lb. of oil, per acre, per year: the pure oil is valued at from 1s. 4d. to 1s. 10d. per lb. in Europe and America.

Cotton.—The cacao-growing districts in Ceylon usually have a rainfall far in excess of that required for cotton, but in other countries where rain falls only during certain months and where a drought can be relied upon, the prospects for cotton as a catch crop in cacao are somewhat favourable. Rain is required during the first two or three months after planting, and irrigation may or may not be required subsequently. The ground should be lined in rows five feet apart and the seeds sown at distances of 18 to 20 inches apart in the rows, 6 lb. of seed usually being sufficient for one acre. Selection of seed is necessary to prevent deterioration from year to year. Plants sown in September-October may flower in January, and the first crop may be picked about six weeks after flowering. According to Mee and Willis*, about 80,000 bolls give 100 lb. of lint and 200 lb. of seed.

Groundnuts.—Groundnuts yield as a single product a crop of 1500 to 3000 lb. of nuts per acre in various countries, the best yielding varieties in Ceylon being the "Mauritius" and

* Cotton, Circular Vol. III., No. 18, R. B. G., Peradeniya, by C. J. C. Mee and J. C. Willis.

"Barbadoes." The nuts are valued at from £8 to £14, according to size, number of seeds per nut, and cleanliness. The seeds yield a valuable oil equal to Olive oil in quality, and the residue after extracting the oil is sold as a manure—groundnut cake—containing 7½ per cent. of nitrogen. The foliage can be used as a green manure or cattle food, and is known as pea-nut hay in America. The leaves and roots contain nearly 1 per cent. of nitrogen, and when mixed with lime form a good plant food for the young cacao trees. The plants are propagated from seeds. The crop ripens in 4 to 6 months, very little machinery is required, and there is a fair demand for large quantities of the oil and cake in Europe.

Cassava.—There are several Para rubber plantations in the Straits and cacao properties in the West Indies, which have practically paid for all working expenses by cultivating varieties of cassava as catch crops for the first three or four years. The cacao may be planted 10, 15, or 20 feet apart, and the cassava 3 to 8 feet apart, both at the same time. The first cassava crop is usually ready for harvesting in 18 months from planting; a second crop may be taken off the land before the end of the fourth year, after which the cassava cultivation generally ceases to be profitable. I have been informed that a crop of tapioca or cassava flour of 1½ to 2 tons, per acre, per crop, is obtainable. The proceeds from these crops more than pay for the upkeep of the cacao.

Cassava thrives best in good soils and can, according to Lewis,* be grown in districts in Ceylon with only 14 inches of rainfall per year or in districts with over 100 inches per year. The plant is propagated from the stem, which is cut into pieces about twelve inches in length, each being planted in a mamoty hole at distances of 3 to 8 feet. The yield in Ceylon is said to be from 8 to 10 tons of tubers per acre, or from 40 to 80 lb. per plant. The cuttings should be planted in wet weather; once established they continue to grow even during periods of severe drought.

Chillies.—These are not cultivated extensively as a catch crop by Europeans in Ceylon, though the successful results obtained in India and the West Indies appear to warrant full consideration. The plant is propagated from seed, the latter being put in well-prepared nurseries until a favourable opportunity occurs to plant. In Ceylon the planting generally begins in April and picking commences in June, and continues for five or six months. According to Drieberg, a chillie plant, with proper attention, lives for a year; the produce per plant varies from 10 to 20 fruits and upwards per picking, and two or more pickings can be got; he further states that in Colombo the ordinary market price of fresh chillies may be put down at 12 cents per 100 and of dry imported ones at

* Manioc, by J. P. Lewis, Government Agent, Northern Province Ceylon.

15 cents per pound of about 750 chillies. The chillies require to be thoroughly dried or cured before being despatched to the market.

Pepper.—The cultivation of pepper among cacao necessitates permanent stumps, preferably of the Dadap plant along which the vine may climb; this product is becoming very remunerative on several cacao estates in Ceylon, and the combination is on the increase.

Future of Intercrops.

The successful and continued cultivation of intercrops with cacao mainly depends on the distance the plants are from one another. The surface roots of the cacao plants should ultimately take possession of the soil, and if interplanted with rubber and tea a wide distance should be adopted in planting, otherwise the cacao and the intercrop will both be stunted. The same applies to camphor, coffee, coconuts, and most other products when planted too close to the cacao root area.

Cacao and Rubber.

The roots of cacao plants do not as closely ramify the soil as those of rubber trees, but they will, if the trees are planted too close, ultimately have to engage in the ordinary struggle for existence. Cacao may be planted 10, 15, or 20 feet apart; the amount of soil on good cacao estates which is comparatively free from roots is often very large, and permits of the growth of other trees on the same acreage. Cacao under rubber will last a very long time if properly distanced, and the protection which the shade of certain rubber trees affords against excessive exposure is greatly in favour of the two products being grown together. In the Matale, Dumbara, Kurunegala, Polgahawela, and Kandy Districts of Ceylon, cacao and rubber as a mixed cultivation is extending. Good results have been obtained on Kepitigalla, Dangan, Wariapolla and many other estates in Matale and on numerous private and public properties in other districts. The planting of both products on the same soil is done in such a way as to allow very free root areas for both species during the first five or six years, many planting the cacao and rubber both twenty feet apart so that there will be approximately 100 rubber and 100 cacao trees per acre. Though the rubber ultimately becomes the stronger component when planted too close, it is surprising how long both products can be successfully grown together. In the cultivation of intercrops with cacao it is essential that both products be planted at the same time, or the cacao first. The illustrations which have been given elsewhere, showing cacao in association with rubber in Ceylon, could be considerably increased but they are sufficient for the purpose; and are worthy of careful study by all cacao planters. Apart from the question of having more than one product to rely on, it is often better, for plant sanitation reasons alone, to have mixed plantations; plants of different genera grown together are often helpful to one another.

Photo by Ivor Etherington.

A MIXED PLANTATION: CACAO AND TEA.

This mixed cultivation is extending so rapidly and is being accompanied by such satisfactory results, that no excuse is necessary for giving a synoptical statement of the three principal species—*Hevea brasiliensis*, *Castilloa elastica*, and *Manihot Glaziovii*,—associated so largely with the cultivation of the cacao tree. The two products—cacao and rubber—are, wherever the climate permits of their successful growth, being regarded as a good and safe combination to select, and in addition to the large acreages of new clearings being thus planted, many cacao planters in Ceylon, Samoa, and the West Indies are gradually supplanting the Erythrinas, Albizzias, and other shade trees on mature cacao estates with one or other of the rubber-producing species.

Comparison of Rubber Trees Grown Among Cacao.

The selection of rubber trees in association with cacao in Ceylon appears to be warranted in many ways, and though it cannot be doubted that the cacao will not thrive as long or as successfully under any of the three rubber trees as it does under trees of *Erythrina lithosperma*, yet the result obtained is satisfactory from the cultivator's point of view. It is obvious that the three forms suggested can be made to produce, during their periods of full foliage, as much shade as may be required, and as they can be planted at approximately the same distance apart, their value is determinable by the yields obtainable per tree, and the composition of the rubber from each. Para rubber trees appear to give a higher yield than either Ceara or Castilloa, and the following table shows the composition of certain samples from each species:—

Ceylon-grown Para, Ceara, and Castilloa Rubber.

	Para Rubber. per cent.	Ceara Rubber. per cent.	Castilloa Rubber. per cent.
Caoutchouc ...	94·60	76·25	86·19
Resin ...	2·66	10·04	12·42
Proteids ...	1·75	8·05	0·87
Ash	0·14	2·46	0·20
Moisture ...	0·85	3·20	0·32

From the standpoint of chemical composition of the raw rubbers one may feel inclined to select *Hevea brasiliensis*; the physical properties of the rubbers are, however, often of equal or greater importance than the chemical constitution and should also be considered. In any case it is clear that in the above three types, the chemical and physical properties of the rubbers obtainable are satisfactory, and it is now necessary to determine the relative suitability of the three species from the standpoint of leaf-fall and duration of the leafless phase.

Duration of Leafless Phase of Para, Ceara, and Castilloa Trees.

It is unfortunate, as far as shading is concerned, that the three rubber trees are not evergreen. The following table shows the time taken from the beginning of defoliation to the production of new leaves for each species, and it is obvious that from the point of view of cacao shade in the hottest and driest part of the year, the Castilloa and Hevea trees offer the most and Ceara trees the least shade to the cacao at this period.

Name.	Leaf-fall		New leaves appeared.	Leafless phase.	Duration of leafless phase.
	Commenced.	Finished.			
Hevea brasiliensis Muell.—Arg.; Tree A;					
1901-02 ...	November	Jan. 6th	Feb. 2nd	26 days	4
Tree B;					
1902 ...	Jan. 1st	Feb. 28th	Feb. 23rd	4 ,,	
1903 ...	Jan. 3rd	Feb. 26th	Mar. 2nd	3 ,,	to
Tree C;					
1903 ...	Sept. 29th	November	November	--	26
Tree D;					
1902 ...	Jan. 4th	Jan. 14th	Jan. 24th	9 ,,	days
1903 ...	Jan. 21st	Feb. 3rd	Feb. 10th	6 ,,	
Manihot Glaziovii, Muell.—Arg.; Tree A;					
1902 ...	Jan. 6th	Mar. 5th	Mar. 10th	4 ,,	4
1904 ...	January	Mar. 10th	Mar. 24th	13 ,,	
1905 ...	February	Mar. 20th	Mar. 28th	7 ,,	to
Tree B;					76
1904 ...	Jan. 21st	Feb. 6th	Apl. 24th	76 ,,	
Tree C; ...	January	February.	Apl. 11th		days
Castilloa elastica Cerv.; Tree A;					
1901 ...	December	Dec. 19th	Dec. 23rd	3 ,,	
1902-03 ...	December	Dec. 24th	Jan. 1st	7 ,,	
Tree B;					
1903 ...	February	Mar. 5th	Mar. 10th	4 ,,	
Tree C;					1 day
1903 ...	March	April	April	--	
Tree D;					to
1904 ...	March	Apl. 8th	Apl. 10th	1 ,,	
Tree E:					9 days
1904 ...	Mar. 5th	Apl. 24th	May 4th	9 ,,	
Tree F;					
1905 ... (two years old).	March	Mch. 3rd	Mch. 6th	2 ,,	

Cacao and Para Rubber.

In Ceylon, the species of rubber plant which has found most favour among planters as an intercrop for cacao is that yielding the Para rubber of commerce. Several estates, possessing cacao and Para rubber plants at the rate of one hundred of each per acre, have obtained very satisfactory results, the cacao coming into bearing in the fourth year and the Para rubber trees in the fifth and sixth years. Estates with Para rubber trees, eight to eleven years old, planted through slightly older cacao, are now obtaining a yield of about two hundred pounds of rubber and the same of cacao, per acre, per year. In the extensions in the combined cacao and rubber cultivation, Para rubber only is being adopted in most parts of Ceylon, and but few planters are interplanting their cacao with trees of Manihot, Funtumia, Ficus, or Castilloa; Para in Ceylon takes the place of Castilloa in the West Indies, and there are very few cacao estates without this species at the present time; under these circumstances a digest of a previous publication* dealing with this species is given in order to supply the necessary information in a synoptical form.

Hevea brasiliensis or Para Rubber.

Growth.—Para rubber is obtained from *Hevea brasiliensis*, a species belonging to the *Euphorbiaceæ* and indigenous to the Amazon valley. Plants were introduced into Ceylon, through Kew, in 1876, and flowered at Henaratgoda for the first time in 1881 when they were five years old, while those at Peradeniya did not flower until 1884. The tree grows rapidly, and in the first few years tends to produce long slender stems, with whorls of foliage at regular distances. By pruning the young buds, the growth in the vertical direction can be checked and lateral shoots encouraged. The increase in circumference takes place at varying rates according to soil, climate, &c., the usual range being from 3 to 6 inches each year when growing alone. The leaves are trifid, large, and lanceolate, and after the tree is two to three years old are shed regularly each year; the trees are leafless for periods varying from 4 to 26 days, each year. The lateral roots form a very compact mass, growing radially at rates varying from 10 to 12 inches or even more, per year, according to local conditions; the tap root may grow to a great length. The flowers appear regularly each year; they are small, green, and scented. The inflorescence is a panicle of small cymes, and possesses male and female flowers. The fruit consists of a three-lobed capsule, and when ripe bursts with a loud report, throwing the seeds a considerable distance. The seeds are speckled brown on the surface and shiny; their compact substance is very rich in oil. The trees produce seeds from the fifth year, the average per mature tree being about 500 each year. About 200,000 seeds weigh one ton.

* *Hevea brasiliensis*, its botany, cultivation, chemistry, and diseases, Colombo, 1906.

Cultivation.—According to many observers Para rubber trees in Brazil grow in a climate which is fairly uniform, the range in temperature being from 74° to 95° F., and in rainfall from 80 to 120 inches. This product is now cultivated in many parts of the tropics, but it is practically confined to the equatorial zone, a few degrees on either side of the equator. It can be grown from sea-level to over 3,000 feet where the average annual mean temperature varies from about 75° to 81° F. It is being grown in parts of Ceylon and the Gold Cast, in association with cacao, where the rainfall is only about 50 inches per year; in Ceylon, Straits, and India it appears to be doing well, where the rainfall ranges between 50 and 200 inches. It is a hardy plant, and experimental cultivations in dry hot districts with irrigation have already been commenced in Ceylon and elsewhere.

The trees grow from 6 to 10 feet in height every year for the first few years, and attain a height of 80 to 90 feet within 30 years. During the first few years the growth is mainly in length, and the rapid increase in girth, varying from 3 to 6 inches per year, is most noticeable after the trees are a few years old. Young trees, which have had their terminal buds removed by thumb-nail pruning or by the knife, have a tendency to throw out lateral branches and thus give rise to an increase in foliage; the growth in height is thereby checked and that of circumference increased. This method of increasing the number of branches and general foliage may or may not be advisable in association with cacao. The plant is propagated mainly from seeds. The seeds or stumps are planted among cacao, at from 15 to 25 feet apart according to local conditions and the objects in view; the most usual plan is to put out the cacao and rubber trees each twenty feet apart, so that there are 100 trees of each kind per acre. Each of the young rubber plants, or the whole estate, should be protected by fencing, otherwise much damage may be done by rats, hares, porcupines, pigs, deer, cattle, etc.

Draining is very essential in swampy patches, and is, of course, beneficial on all estates. Holing on as liberal a scale as possible is practised. Though this species grows best in good soils it is noteworthy that it thrives in soils relatively poor in physical and chemical properties. The leaves are very rich in potash, nitrogen, and lime, and may be turned into the soil for manurial purposes.

Tapping.—The latex is obtained from the trunk of the tree by making incisions and conducting the exudations to a basal receptacle. Over a score of patent tapping knives have been recently described, many of which are constructed so as to avoid wasteful excision of the cortical tissues or penetration of the cambium. The incisions may take the form of single oblique cuts, V's, the half or full herring-bone, or the half or full spiral; the latter methods have come into prominence during the last year. Before incisions are made the areas to be tapped are cleaned and carefully defined.

Photo by C. A. C. Colombo.

CACAO AND PARA RUBBER IN BEARING.

DANGAN ESTATE, RUBBER PLANTATIONS, LTD., MATALE.

During collecting operations various appliances and chemicals are used to aid the flow of the latex, and prevent the closing of the latex tubes until they are more or less empty; though good results have already been obtained, the methods of collecting the latex over large acreages are likely to be greatly improved in the near future. The trees are usually tapped from the base up to six or ten feet; large trees can be tapped to a much greater height. The latex usually increases up to the 3rd or even the 14th tapping; Parkin's results show a rise in yield from 61 c.c. for the first tapping to 449 c.c. for the 14th tapping. The rubber prepared from latex obtained from different levels of thirty-year-old trees, from the base to fifty feet, is usually quite good, but high tapping is not anticipated for the rubber trees which are now being planted.

The trees are tapped according to size or age. In the Amazon district the Para rubber trees are said to require 15 years to come to tapping maturity in open plantations and 25 years in the forest, and in Para the trees are sometimes tapped for the first time when they have a circumference of 18 to 24 inches. The rubber obtained from Para rubber trees two, four, six, eight, ten, twelve, and thirty years old does not differ conspicuously in chemical composition, though the samples from the young trees usually show a tendency to become sticky and lose their good qualities. In most countries the age of the trees when they can first be tapped is of minor importance, and a circumference of 20 to 24 inches, a yard from the ground, is commonly accepted as a size when the trees may be tapped for the first time. Tapping is usually done in the early morning and evening when the temperature is low, and is carried on throughout most months of the year. The frequency of tapping varies, some trees being tapped every alternate day, others during alternate months, and some only during certain seasons.

Yield.—The yield shows a considerable variation, according to the extent of the tapping area per tree, and the methods employed. Individual trees have given from 2 to 25 lb. of dry rubber per tree in twelve months, but fairly large acreages have yielded quantities varying from $\frac{3}{4}$ lb. to $5\frac{1}{2}$ lb. of dry rubber per tree, per year, for one or more years. When grown with cacao, a yield of half to nearly three lb. of rubber, per tree, per year, has been obtained.

The latex is white or pale yellow in colour, and is slightly alkaline or neutral when it issues from the tree. Mechanical impurities, such as pieces of bark, sand, &c., are usually present, but can be removed by straining. The latex shows a great variation in its composition, particularly in the percentage of water; it is usually estimated to possess from 52 to 56 per cent. of water, 32 to 41 per cent. of caoutchouc, 1 to 3 per cent. of proteids or albuminoids, and varying quantities of resins, salts, &c. It readily

mixes with water or any alkaline solutions such as ammonia, ammonium sulphide, &c., and is not coagulated by freezing or boiling, though acids readily bring about this change.

Coagulation.—The pure rubber is obtained from the latex by processes of straining, coagulating, washing, rolling, and drying. Coagulation appears to be possible owing to the presence of the proteid matters in the latex; these remain in solution so long as the mixture is neutral or alkaline, but are precipitated when the solution becomes acid. If latex is allowed to stand for some time the proteid matter decomposes, and acidity sufficient to lead to coagulation is developed, but this may be delayed by the use of formalin or ammonia. The coagulated proteid is considered by many persons to act as a clarifier and to carry with it the suspended globules of caoutchouc and other bodies. On estates where the daily quantity of latex is small, it is usually put into shallow pans and allowed to set with or without the addition of acid. The cake or sheet of rubber obtained by such a process is then washed, rolled, and dried, and finally placed on the market as biscuit, sheet or block rubber. The addition of certain chemical reagents to the latex, hot or cold, brings about coagulation: dilute mineral acids, such as acetic acid and tannic acid are particularly active. Coagulation may also be hastened by exposing the latex to heat and the products of combustion of a fire, the latex being coagulated fractionally by such a process, and the finished product, when properly manufactured, is said to be less liable to putrefaction than the rubber prepared by many other methods. The smoke from burning palm nuts (*Attalea excelsa*, Mart., *and Maximiliana regia*, Mart.,) contains, among other substances, small quantities of acetic acid, acetone, and creosote. The acetic acid is probably the agent responsible for effecting the coagulation; the other substances, particularly the creosote, are absorbed, the latter acting as an antiseptic. The decomposition of the albuminous or proteid substances in the latex may be prevented by the addition of suitable antiseptic reagents to the latex when the rubber is prepared in other ways, though quickness in drying and complete extraction of the moisture from freshly-coagulated rubber are often sufficient to bring about the same result.

If antiseptic substances have been added the rubber will keep well though in a wet state. Coagulation by chemical reagents is commonly adopted on estates. Many compounds such as picric acid would rapidly coagulate the proteids, but the effect on the resulting rubber would be bad. It has been shown that many acids may be used in the coagulating process; it is unnecessary to do more than mention those which have, from practical experience, been proved more or less acceptable to producers in the tropics and manufacturers in Europe. Acetic acid—this is cheap, always procurable, is not dangerous to handle, and is as effective as formic acid. Formic acid, tannic acid, and mercuric chloride may also be used.

The rubber may be dried in a vacuum chamber or in the house used for curing the cacao. The curing house should not be heated much higher than 120 °F., as otherwise the rubber may become soft and sticky,

Cacao and Castilloa or Panama Rubber.

Castilloa or Panama rubber is obtained from a tree native to tropical America, know as *Castilloa elastica*, Cerv. The success with which this species has been grown in association with cacao in Mexico, Grenada, St. Lucia, Tobago, Dominica, Montserrat, and other West Indian Islands has aroused considerable interest, though in Ceylon preference seems to be given to Para rather than to *Castilloa elastica* as a profitable shade tree to be grown in conjunction with cacao.

Growth.—The Castilloa rubber tree grows rapidly during the first few years, producing a straight bole with a crown of leaves above; specimens, in Ceylon, when only three years old may be thirty feet high and have a girth of twenty inches a yard from the ground. Six-year-old trees at Henaratgoda have a height of 46 feet and a circumference of 26 inches. Trees in Dominica, when 13 years old, are reported to be 55 feet in height and 67 inches in circumference. The permanent branches are not as low as in Ceara trees, but in four years, when planted 15 feet apart, the ends meet and the cacao plants and ground beneath are well shaded. The young branches on the lower parts of the stem die back. The tree loses all its leaves annually after the second or third year, though the leafless phase is shorter than that of Ceara rubber trees.

Propagation.—The plant can be best propagated from seeds, and the use of seed at stake or of basket plants is recommended; this species is not as successful as Para or Ceara rubber when planted from stumps or cuttings. The tree is perhaps not as hardy as either of the forms just mentioned, and care must be exercised in planting operations if success is desired. The climates in the Uva province and Dumbara and Matale districts of Ceylon appear to be suitable for its cultivation, and its distribution is almost the same as that of cacao in this island. It grows best where the minimum temperature is never below 60° F., and in districts with a well-distributed rainfall of 50 to 80 inches. The Castilloa trees are planted at about 20 feet apart in cacao, in Ceylon, and 30 feet apart in other countries.

The collecting of the latex is done in very much the same manner as with Para rubber, simple incisions or parings and prickings of the bark being sufficient to cause the latex to flow. In Ceylon it has not been a great success, the yield from trees having a circumference of 30 inches and over being usually poor. Old trees in Dominica are reported to give about 1 lb. of dry rubber each, per year, whilst others are described as yielding from 9 to 40 ounces of rubber annually.

The annual shedding of the leaves provides a large quantity of organic matter, but occurs during the driest and hottest months of the year when the cacao plants require shade. Generally the leaf-fall commences at any time between December and March and ends in December to April, the new leaves appearing after the trees have been leafless for from one to nine days.

When planted among cacao it is said to begin yielding sound rubber in its sixth or seventh year. The quantities obtainable in Ceylon are insignificant compared with those from *Hevea brasiliensis*, and on several cacao estates the Castilloa trees have actually been felled and Hevea stumps planted to take their place. Hudson, at St. Lucia, West Indies, has recently condemned Castilloa and recommended *Hevea brasiliensis* for growing in association with cacao in that country.

It is asserted by some authorities that the combination of Castilloa rubber trees and cacao is not as good as when additional forest trees are planted, the latter offering a desirable shade for the Castilloa trees. Species of Erythrina and Albizzia may be used for such purposes and planted at about double the distance of the Castilloa; on such mixed plantations the cacao plants might be planted from 12 to 15 feet apart, the Castilloa trees 25 to 30 feet apart, and the Erythrinas 40 to 50 feet apart.

Cacao and Ceara Rubber Trees.

Ceara rubber is obtained from the stems and branches of *Manihot Glaziovii*, Muell.-Arg., a native of Brazil. The plant can be easily propagated from cuttings or seeds, though the latter require to be filed before being sown in the nursery; nursery plants can be effectively transplanted in rainy weather. The tree grows very rapidly, many specimens attaining a height of 20 to 30 feet and a circumference of 15 to 20 inches in three years. The tree does not usually attain a height much above 30 or 40 feet, branches usually occurring at ten or fifteen feet from the ground. On account of its rapid growth, low branching, and large palmately-lobed leaves, the young trees soon afford a strong shade for the cacao plants. Flowers are produced in the second year, and the fruits, when ripe, burst with a loud report, scattering the seeds a considerable distance. It is a common experience to find that, when the shrubby growth under trees of Ceara rubber has been cleared, the whole ground, for very long distances, becomes rapidly carpeted with the young seeds of Manihot.

Ceara rubber trees can be grown at elevations ranging from a few feet to over 4,000 feet above sea-level, in climates having a rainfall varying from 30 to 200 inches and a temperature of 60° to 90° F. This species has a much wider range for its possible cultivation than either Castilloa, Para, Funtumia, Ficus, Sapium or Landolphia etc., on account of its quick growth and drought-resisting characters. It has consequently found its way to every province in Ceylon, and to many islands and territories in the tropics.

Under cultivation the trees cannot usually be systematically tapped before they are six or seven years old, though in Brazil the rubber appears to be sometimes extracted from trees having a circumference of less than 20 inches. Before tapping it is customary to remove the outer smooth, silvery bark, an operation rapidly and easily performed; after peeling off the outer dry bark the fresh inner bark is then tapped, either on the V, herring-bone or spiral system. The results obtained in some parts of Ceylon are not very encouraging, owing to the yields being relatively poor and many of the trees dying after tapping. Several 10 to 20-year-old trees were tapped at Peradeniya during 1905 and 1906, and gave in three months 85, 108, 60, 52, 169, 65, 106, and 183 grams only of dry rubber, per tree, during that period. When the dry weather sets in the inner bark rapidly dries, and is apt to peel away and expose the wood beneath, and for this reason it may be found advantageous to leave the dry outer bark intact and to tap by making chisel incisions only.

Generally speaking, Ceara rubber trees appear to give better results in dry zones, and may be more suitable for cacao districts where the rainfall is too small for other rubbers. The rubber is of good quality, though the yields obtained by tapping do not appear to be very satisfactory; the trees appear to stand lopping better than ordinary tapping, and if a process of extraction by macerating the dried bark can be successfully evolved, the prospects for this rubber in association with cacao may be improved.

The trees shed all their leaves annually, and though the foliage thus returned to the soil may be of considerable value to the cacao plants, the leafless condition is unfortunately very prolonged, and occurs only during the hottest and dryest months in the year. At Peradeniya many observations have been made on these trees; the leaf-fall usually commences in January or February and ends in February or March, new leaves appearing in March or April after the trees have been leafless for periods varying from 4 to 76 days.

Ceara rubber trees were, several years ago, extensively planted on estates in Ceylon, and gave a good shade to the cacao plants and soil in a few years' time. If planted twenty feet apart in cacao, their roots soon ramify through the greater part of the soil and many planters consider that the effect is much more detrimental than when either Para or Castilloa trees are similarly interplanted. On most cacao estates in Ceylon and in the West Indies, Ceara rubber trees are rarely cultivated in districts where either of the other rubber trees will thrive; in parts of tropical America where cacao is irrigated, the planting of Ceara, in preference to Para or Castilloa, appears to be extending.

Cacao and Funtumia Rubbers.

The cultivation of cacao and *Funtumia* (*Kicksia*) rubber trees, though not known on cacao properties in Ceylon, is often met with

in parts of Africa and the West Indies. There are many species known, and among the more important may be mentioned *Funtumia africana*, Preuss, *F. africana*, Benth., *F. Zenkeri*, K. Sch., *F. latifolia*, Stapf. *F. Gilletii*, de Wild, *F. Schefflert*, K. Sch., *F. congolana*, de Wild, and *F. elastica*, Stapf. Many of these species grow to a considerable height, but their branch system is generally very poor, and is not of that extensive character which would make it an effective shade for cacao except when closely planted.

The species known as *Funtumia elastica*, Stapf, (*Kicksia elastica*, Preuss) is the one usually grown in association with cacao. In the wild state it often occurs in clusters, some individuals of which attain a height of 30 metres; the trees have cylindrical trunks and branch systems, and do not appear to have a very exhausting effect on the soil. In the wild state they are supposed to be first tapped when about six years old, and according to Schlecher* may yield, by native methods of tapping, from 500 to 750 grams of rubber, per tree, per year. One tree, only seven years old, has, by careful tapping, yielded three litres of latex from which two kilos of rubber were obtained.

The latex does not coagulate on treatment with mineral or organic acids, or with alkalies, but is coagulated by the addition of water, alcohol, or by boiling. The latex contains from 31 to 35 per cent. of caoutchouc, and some samples of rubber—known as the Lagos silk rubber—possess 10·57 per cent. of water, 82·39 per cent. of caoutchouc, 6·35 per cent. of resins and 0·69 per cent. of ash constituents.

Funtumia elastica is, therefore, a tree which will yield a good rubber and will grow in association with other forest types, but the results obtainable in conjunction with cacao are at the present time too meagre to allow of definite recommendations being made.

Cacao as Part of a Mixed Plantation.

So far only the interplanting of cacao with various rubber-producing species has been discussed. It is also feasible to arrange the cacao and rubber plants not as components on the same soil, but in separate batches so that the rows of rubber trees form distinct belts between parallel groups of cacao trees, and to some extent serve as wind-belts or means of checking the distribution of injurious insects and fungi. If the cacao is arranged as part of such a series, shade trees might be necessary; but the proximity of belts of rubber trees would to some extent obviate the necessity for additional wind-belt trees. As a suggested plan, capable of modification according to local conditions, the following might be useful:—Plant five or more lines of cacao, the lines to be ten to fifteen feet apart, with the plants in each line distanced according

* Henri Jumelle, Les Plantes à Caoutchouc et à Gutta, Paris, 1903.

to requirements; interplant these with trees of *Erythrina lithosperma* if shade trees are necessary; then plant three to six lines of rubber, the lines to be ten to twenty feet apart. The rubber trees in one line might be all of the same species, but adjacent lines might, if considered advisable, be composed of different species, say Para, Ceara and Castilloa; alternating lines of these species would form a very compact belt, the low-branched Ceara below, high Para trees uppermost, and the Castilloa intermediate in height, and be to some extent shaded. This is only by way of a suggestion; the remarks are not based on the results of experience.

Acreage in Cacao and Other Products.

The interplanting of cacao with numerous products has now been shown to be possible. At the present time the total acreage under cacao in Ceylon is estimated* at about 34,000 acres, including native gardens. The greater part of this is in cacao alone—over 20,000 acres; the next largest is cacao and and rubber combined —7,852 acres; cacao and coconuts—2056 acres; cacao and tea– 817 acres, and cacao and coffee—578 acres. It is quite probable that the acreage at present in cacao alone will ultimately become largely a combined cultivation of cacao and rubber; the acreage representing cacao with coconuts, tea, and coffee, is not likely to increase very rapidly, if at all.

* Ferguson's Ceylon Handbook and Directory, July, 1906.

CHAPTER VIII.

GENERAL OPERATIONS ON CACAO PLANTATIONS.

Weeding of Cacao Estates.

IN Ceylon it is customary to interplant the young cacao with permanent arborescent types which subsequently provide shade, and assist in keeping the growth of weeds at the minimum; the land is systematically weeded by contract coolies who are paid at rates varying from 7 to 12 rupees (Rupees 15 = £1) per acre, per year, and by this means the land is invariably kept clean, and the soil exposed to the sun and rain especially for the first few years of the plantation's existence. On some estates, the newly-planted areas are sown with seeds of various herbaceous green manure plants which, on account of their rapid growth, help to keep the weeds in check; on some properties in Ceylon, catch crops are grown which serve a similar purpose.

In parts of Samoa it is the custom to keep the ground around the cacao trees free from weeds, the long dry season allowing the planters to do this work much more cheaply than in Cameroon, where a similar mode is often adopted. In Tobago it is recommended to keep the ground free from weeds so as to prevent the young cacao plants from being covered with other growths; weeding round the cacao trees is done by hand, but in the middle of the lines hoeing is carried out. In Trinidad it appears to be the custom to weed about twice each year; Hart recommends hoeing instead of cutlassing the weeds in the younger stages of the plantation. In other parts of the West Indies the question of weeding does not appear to have been settled, many authorities recommending clean weeding, others weeding only around each tree, and others turning in all the weeds over the whole plantation at regular intervals.

The Pruning of Cacao: Pruning in Ceylon.

The systematic pruning of healthy cacao trees is an operation which is hardly known or very rarely practised in Ceylon, though it is considered to be of great importance in other cacao-growing countries. When the cacao trees are very liable to diseases which rapidly lead to the death of the stem and off-shoots, the removal of the the affected tissues is often necessary at very frequent intervals. In many parts of Ceylon, before the method of exterminating the

cacao disease on the stem was properly understood, the extensive destruction of diseased stems and branches removed more than did the systematic pruning of healthy tissues in other countries; in most cases the Ceylon cacao planters were only too glad to allow any suckers or lateral branches to develop in order to provide the foliage necessary for the continuance of the life of the tree. Now, however, it is well-known that the diseases leading to the extinction of stems and branches, in Ceylon, may be effectively checked in their early stages by repeated but less drastic excision of diseased areas, and the trees may therefore be allowed to develop in a way more characteristic of healthy cacao trees under cultivation.

Ordinary cacao trees, if allowed to grow uninterruptedly, may produce long, tall, woody stems, low and bending branches, and throw off an indefinite number of suckers at various points of the main stem, resulting in the formation of irregular and reputed inferior fruiting trees. The pruning of cacao trees has for its object the production of more symmetrical trees, the removal of weak bending branches and suckers, and the development and maturing of a single main stem or old fruit-wood.

Symmetry of Cacao Trees and Plantations.

Foliage and Roots.—There is a deep-rooted belief among many planters that the area covered by the spread of the branches and the foliage is the same as that of the root system, and it has been propounded* that the maintainence of equilibrium between the crown of foliage and the spread of the root system is one of the important objects of pruning cacao trees. Observations on the spread of the root and foliar systems of cacao and other trees, in Ceylon, do not, however, support the idea except in a very approximate manner, the development of the cacao roots being very often such as to traverse the soil for considerable distances beyond the extreme points of the best developed branches on old mature trees. Such conditions occur, very frequently, on estates where the root system has not suffered from pruning due to too frequent or drastic trenching, and where the pruning of the branches of the cacao trees has been carried out. The penetration of the thin strong roots to great distances is almost unlimited in a free soil, whereas the spreading of the foliage may be stopped by branches of adjacent trees. Exception must therefore be taken to this idea of equal development of two parts of the vegetative system as a point of great advantage attendant upon the branch-pruning operation. An unequal development of these parts is the most common condition on the average cacao estate, and in that system of pruning which has for its object the production of tall trees the want of equilibrium is considerably enhanced.

* Etwas über das Schneiden der Kakaobäume, by C. Zwingenberger, Der Tropenpflanzer, No. 6, June, 1904.

Symmetry in Foliage.—When, however, one considers the development of a symmetrical stem and branch system alone, one can discern the ease and certainty with which it may be obtained and the advantages accruing from such a condition. A symmetrical tree will allow free access to air and light, and also perhaps to other agencies concerned in effecting pollination; and at the same time permit of a more detailed survey of parts of the tree during plant sanitation and crop-gathering operations. Trees with irregular branches at all angles are often much damaged when manuring, collecting, spraying, and excising operations are being carried out.

A Regular Plantation.—The production of a plantation with trees similar in size and habit is sometimes aimed at by planters who are enthusiastic over the production of symmetrical trees, but it is a condition, which, apart from its uniform appearance, has little to recommend it. The thousands of cacao trees on any plantation are different in their constitution and in their power to respond to different environments; they are not all treated alike in their career from the nursery to maturity, and it is therefore only natural to expect that much unevenness in size and habit will be manifest. It is difficult to understand on what commercial grounds the conversion of all the cacao trees to a conventional size or type, involving a suppression of their individual potentialities, is recommended; each tree or variety should, in the writer's opinion, be allowed to develop in its own characteristic way, and pruning be considered in relation to its parts and not to the evenness of the plantation. In some countries, or on certain soils, the different varieties grow in different ways. Strunk states that the Amelonado variety in Cameroon, though growing luxuriantly, does not produce wood as strong as that of the Calabacillo and Forastero varieties, and the branches habitually bend towards the earth; and it is asserted that this variety may be distinguished from the rest by its vegetative habit even when there is not a single fruit on it; many planters prune off all the bending branches, while others retain them and provide temporary supports for such weak parts. The differences between the vegetative characters of the Caracas and types of Forastero are obviously very great, and the policy of meting out exactly the same treatment is difficult to understand.

Pruning Operations.

Pruning may be done in order to check the growth in certain directions or to remove weak and undesirable suckers.

Initial Pruning.—It is generally conceded that very young trees should not be pruned as the removal of foliage at too early an age may appreciably affect the future health and vigour of the tree. Trees when two years old require attention, and if they have branched near the base the weaker shoots are sometimes removed*, and only the strongest stem is allowed to survive. The

* C. Zwingenberger, l. c.

results which follow this treatment have been questioned by Strunk,* who pointed out that the desired end would only be attained if the remaining strong shoot, after growing to a desired height, forked in the required manner. The main stem can, however, be thumb-nail pruned or pinched at any height, and the lateral branches which subsequently appear be removed or encouraged according to requirements; in this way the branch system may be made to develop in any direction and produce a more or less symmetrical tree. There has been much discussion as to the best height for the first branches, though generally a clean stem of four to six feet in length is considered advisable. The illustrations published by Strunk† show a six-year-old specimen of the Calabacillo variety growing in the Botanic Garden, Victoria, with one central stem forked into four or more branches at a height of about four feet from the ground; other illustrations show trees, 15 and 25 years old and of the Amelonado variety, with similar branches much bent or inclined and attaining a considerable height, but allowing free access to air and light on all sides. Once the tree has been forked at the proper height, its subsequent development is largely controlled by pinching off the terminal buds of the branches in such a manner as to produce a symmetrical crown of branches and foliage.

Subsequent Pruning.—When once the tree has developed into the required size and shape systematic pruning commences, and all weak branches, or those bending to the ground, and dry dead material, are regularly removed. In this operation it is necessary that the living material should be pruned gently and frequently, and large branches should rarely be removed. Overlapping branches should be pruned while young. In some countries bad results have followed too violent pruning; according to Zwingenberger, the pruning in Cameroon, which dated from the return of Dr. Preuss from his tour of investigation in Central and South America, was at first done too vigorously, with evil effects, but after the introduction of cacao planters from Surinam, proper methods were adopted and good results obtained thereby.

The desirable ultimate size and shape of the trees is a matter of opinion, and many believe that the growth in height of the tertiary branches should never be checked, on the ground that the bigger the tree the larger the crop.

The pruning should be carried out with a clean sharp knife; in most countries the covering of the cut surface with tar, mud, etc., is recommended. Hart‡ recommends the use of a mixture of coal tar and whale oil in equal proportions as an effective compound for such dressings. The cuts should be made as

* Zur des Beschneidens der Kakaobäume in Kamerun, by Dr. Strunk, Der Tropenpflanzer, June, 1905.

† Der Tropenpflanzer, June, 1905.

‡ Hart, West Indian Bulletin, Barbadoes, Vol. 1., No. 4.

close to the remaining stem and as smooth as possible, in order to obviate the rotting of stumps or the production of resting places for germs and water; according to Hart it is a practice in the West Indies to leave a small stump of an inch or two in length, though it is not to be recommended.

When to Prune.

The time of year when pruning should be carried out depends upon the prevailing seasons and their relation to the periodicity of the cacao tree. Hart states that in Grenada the pruning might be undertaken, after the crop has been gathered, in the months of February, March, and April. Zwingenberger states that in Cameroon the pruning, except the removal of suckers, should not be carried on during the active vegetative periods, April-May and September-November. In Ceylon the work can be done best after the crop time during the dry months from January to April, as, though it is a period when vegetative activity may be pronounced, the excision of diseased areas of the stem is usually then undertaken. On some Ceylon estates an inspection of the cacao trees is made every month of the year and all diseased tissues excised, but on most properties the trees receive close attention only during the dry hot season; on account of the absence of crop and the impossibility of carrying on planting operations the work of excision of diseased stem tissues and the pruning of weak and dead wood can best be carried out during these months.

Pruning Cacao Trees in Trinidad.

In Trinidad the cacao trees are often allowed to grow without interruption until they fork naturally; the forking usually takes place, according to Preuss, at a height of thirty to sixty inches (75 cm. to 1·5 metres), four or five whorled branches being given off. It is seldom that all the five branches are allowed to remain, one or two usually being removed, according to the nature of the plant; when the varieties are characteristically strongly built, four or five branches may be retained, but if the type is a weaker one only three branches are retained. In Trinidad, the pruning of the mature trees is done mainly after crop time in July or January, when the two important crop periods occur in June and December.

Hart states that there should be only three or four primary branches left on each cacao tree, and that these should be encouraged to develop secondary branches at regular distances; he also points out that in the primary stages thumb-nail pruning or pinching should be done instead of allowing the wood to develop to a considerable size and then cutting down the material by the knife. The precautions to be considered in pruning are well described by Hart, to whose work reference should be made.

Pruning in Cameroon.

Owing to the efforts of Preuss, the pruning of cacao in Cameroon has been the subject of many experiments, and according to Strunk

Photo by Ivor Etherington.

CACAO TREE FROM SUCKERS.

there are four more or less distinct methods of pruning being tried. In the first method the object of the planter is to produce, by means of pinching and light pruning, an uniform round crown of foliage supported on a series of three or four branches; this was introduced by Preuss to Cameroon on his return from South America: the second method consists in removing only the dried wood and the suckers or water-shoots: the third provides for the removal of the same and the removal of all branches which overlap or are in contact: the fourth method has for its primary object the production of tall cacao trees, and is achieved by the removal of all outwardly spreading branches when the plants are young. The last method is in opposition to the first, and is carried out by planters who believe in increasing the high wood for fruit production irrespective of the difficulty of carrying out crop-collecting and other operations.

Though the pruning of weak branches appears to be an operation likely to be of value there are many cacao planters of experience who believe in retaining branches which bend towards the ground and giving them every assistance by means of wooden supports, etc., in the belief that such low stems ultimately bear a fair proportion of crop which can be collected without doing damage to the tree.

Pruning Suckers.

During most months of the year and especially in periods of increased vegetative activity the stems are apt to throw off lateral shoots in profusion; these shoots grow upwards rapidly and often to a great height before forking or producing flowers, and on account of their interference with parts of the stem and branch system and their reputed exhausting character are usually removed. The suspicion against these "suckers," "water-shoots", —or as they are often called "gormandisers"—is so great that instructions are usually given to remove them at every opportunity and at all times of the year; the pruning of these tissues therefore differs from that of other parts of the plant.

There can be no doubt that the production of large numbers of suckers destroys all uniformity, and gives rise to considerable difficulty in subsequent operations. But it should be pointed out that in many parts of Ceylon the development and cultivation of suckers has been the means of saving many cacao estates. When the "canker" disease has got a good hold of the stem it is often impossible to eradicate it without resorting to the removal of the stem and all its branches, this serious operation usually being made immediately above the point of issue of a sucker; the latter is then allowed to develop as the main stem of the tree. The suckers have a tendency to fork into three or more branches, and when they arise from the base of a stem, the height of the forking is often one which subsequently allows of the development of a very uniform tree. Examples can be quoted of suckers becoming diseased, and they in turn being sawn off at a

particular height, and secondary suckers allowed to develop in place of the original stem and sucker; the sympodial stems—consisting of a basal part of the original stem, and the primary and secondary suckers above—produce far from discouraging crops.

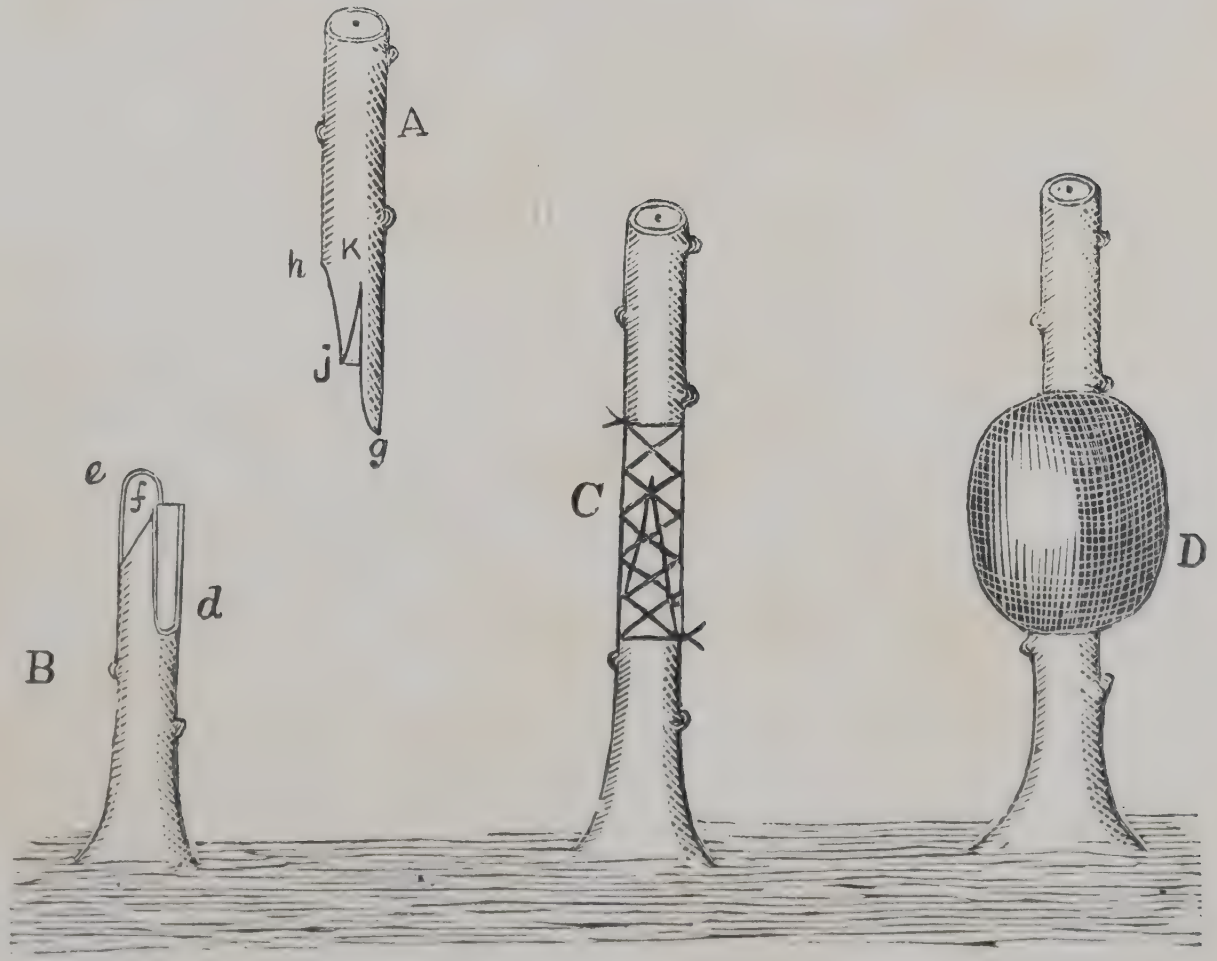
The reputed non-productive character of suckers seems to have taken a firm hold in the minds of cacao planters in the East and West Indies; to some extent the idea is correct, but in order to impress upon the reader the possibilities with suckers when properly tended, the figures of yield and number of cacao trees with and without suckers on plots at the Experiment Station, Peradeniya, are given below. In 1902, over 90 per cent. of the cacao trees on the plots in question were suffering from "canker," and in the eradication of the latter many of the stems were felled near the base and others seriously amputated. The crops which have been obtained since 1902 have mainly been derived from the suckers which were already present or subsequently developed, and an illustration given elsewhere will show a typical Forastero tree, without main stem but with several suckers, which has given considerably over 100 fruits, per year, during the last two years.

Plots.	Number of Cacao Trees.		Number of Fruits per acre.	
	With suckers.	Without suckers.	1903	1904
A	422	98	10,334	13,966
B	280	69	8,194	11,614
C	370	141	6,947	8,212
Total ...	1,072	308	25,475	33,792

These plots, though comprised of such a large number of cacao trees developed from suckers, have given an average annual yield of nearly 10,000 fruits per acre.

Grafting Cacao.

Objects of Grafting Cacao.—The grafting of one variety on to another so commonly practised in Europe is almost entirely neglected on cacao estates in the tropics, though Hart, Thierry, and others have carried out several cacao grafting experiments with success. The average cacao estate possesses trees differing greatly in their vegetative and crop-producing powers, the many varieties blend one into another, and anything but a homogenous crop of seeds is usually found. The grafting of varieties known for their high quality of cacao seeds on to others with the best vegetative characters is likely to be accompanied, as far as one can judge from other fruit trees, by an increase in the quantity and quality of the crop, a more vigorous vegetative growth, and a general evenness of characters.



WHIP AND TONGUE OR SPLICE GRAFTING, (FIG. 1.)

both vegetative and reproductive. Only those varieties having mainly white and plump seeds such as the Nicaraguan or Caracas should be grafted on to the more vigorous Forastero, Amelonado or Calabacillo varieties and a more approximate evenness in quality of collected cacao can then be assured. All the varieties appear to be capable of being grafted,* and Hart states that experiments in the grafting of *Theobroma Cacao* on to stocks of *Theobroma bicolor*, and *Cola acuminata*, have been made; when done by the inarching method, in the seedling state, appear to give satisfactory results.

Methods of Grafting.

The modes of grafting are numerous, but the following account and illustrations † reproduced by favour of Mr. J. Knighton Nock, Curator of the Hakgala Gardens, Ceylon, will be sufficient for our purpose:—"1. Whip, Tongue, or Splice Grafting—the common and generally the most successful—is illustrated in Fig. 1. *A* represents the scion, *B* the stock, *C* the two fitted together, and *D* the whole finished and moulded. To begin operations, make a clean slanting cut on the stock *B* from *d* to *e*, just above a bud if possible, which will act as a preventive to the wood dying back. Then take the scion *A*, which must have at least three to four buds (one being at the lower extremity to assist the union) and cut it from *h* to *g* in a way corresponding to that on the stock; it is better to have it too thick than too thin to start with, as in the former case the surface can be shaved off smoothly so as to fit well. Next cut a thin tongue from *j* to *k* which completes the preparation of the scion. The stock should now be cut at *f*, so that *j k* (the tongue of the scion) fits exactly, and when pressed together the inner barks come into contact on one side at least. The slit *f* in the stock acts as a support to the graft and should be made as near the top as possible, as, if made lower down, it would tend to interrupt the flow of sap."

"It now remains to prevent air and sun from reaching the cuts. Take a little clay and rub it well round, making a large ball, and then press firmly so as to make it taper to the top and bottom in the shape of an egg as shown in *D*. By dipping the hand in the ashes and re-moulding the ball a nice finish can be given."

2. Saddle-Grafting. (Fig. 2.) "Success in this method depends on the stock and scion being of more or less equal thickness. The stock *a* is cut into a wedge, sloping on both sides to *c*, and the scion *b* is slit up the middle and enough wood shaved off to make it fit exactly. A sharp narrow-bladed knife should be used for this work. Tie and mould as in mode No. 1, taking care that the inner barks come into contact on one side at least. It is very important to see that the slit in the scion does not extend above *c*. Wedge-grafting is sometimes classed with this, the only difference being that the cuts in the scion and stock are reversed."

* Hart, Annual Report, Botanic Garden, Trinidad, 1902.
† Tropical Agriculturist, Colombo, August, 1905.

3. Grafting by Approach or Inarching.—"This is nature's only mode, and may occasionally be seen in gardens or forests where branches of two trees have rubbed together and become united. It is one of the most certain means of propagating kinds that will not readily root from a cutting or respond to other methods of grafting. The difficulty is that the scion must either be in a movable pot (see Fig. 3, *A* being the scion and *B* the stock), or be planted in close proximity to the plant it is intended to graft it on to, or both must be in pots. It differs from other grafting in that the two parts are nourished by their own roots until a perfect union has been effected, when the scion is detached. In some gardens this method is adopted to form an arch over a road or path, two trees of the kind being planted one on each side and "inarched" when they have reached the desired height. The principles are the same, success depending on the inner bark being brought into contact. Similar portions of bark and wood, about three inches in length, should be removed from each at points where both can conveniently be made to meet, and bound carefully together and moulded as in No. 1. Stakes should be firmly fixed in the ground to support each. When a union has been formed the scion may be gradually cut and shaved off from x to z. The growth of the buds on the upper extremity of the stock should be checked by nipping them off when the growth is vigorous; this portion must be detached as gradually as the lower portion of the scion. A tongue is sometimes cut in the scion to fit into a corresponding notch on the stock. When the scion is not available in a pot, or the plants are not close together, a long shoot may be cut and nourishment afforded by placing its extremity in a vessel kept full of water; this, however, is not very effective." The inarching method appears to be the most satisfactory for cacao when carried out at the seedling stage.

Precautions.

It is necessary that every protection should be given to the scion during the early stages against exposure which might lead to rapid evaporation; shading the scion or enclosing the whole in glass tubes to retain the moisture and exclude air is sometimes adopted. The necessity for moisture is mentioned by Thierry, Nock, and others; when balls of clay are used, they should be kept in a moist condition, and only removed when growth of the graft necessitates such a step.

When to Graft.—It is important to know at what age of the cacao plants grafting should be done. The operation may be carried out by the (1) whip, tongue or splice grafting, and the (2) saddle grafting when the trees are of a considerable age, but if the grafting by approach or inarching is intended, one and preferably both of the plants should be in baskets, bamboos or earthenware pots. Thierry recommends, even when the grafting is not done by the "approach" method, that the "stock" or rooted plants should be in bamboo pots and the operation be performed after the young stock has thrown out its first leaves above the cotyledon, and

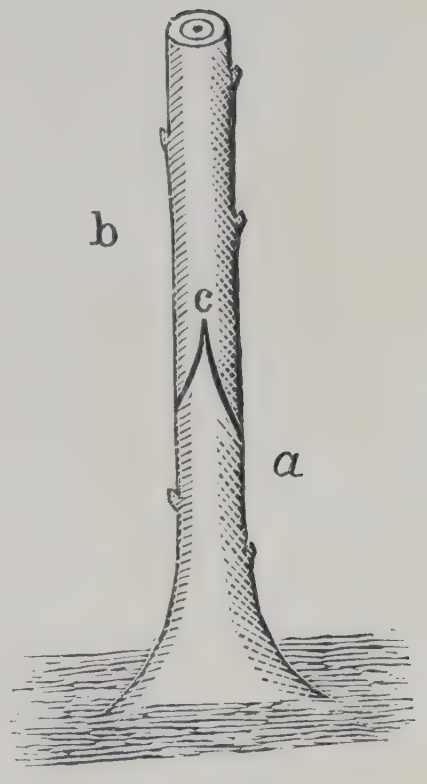


FIG. 2,
SADDLE GRAFTING

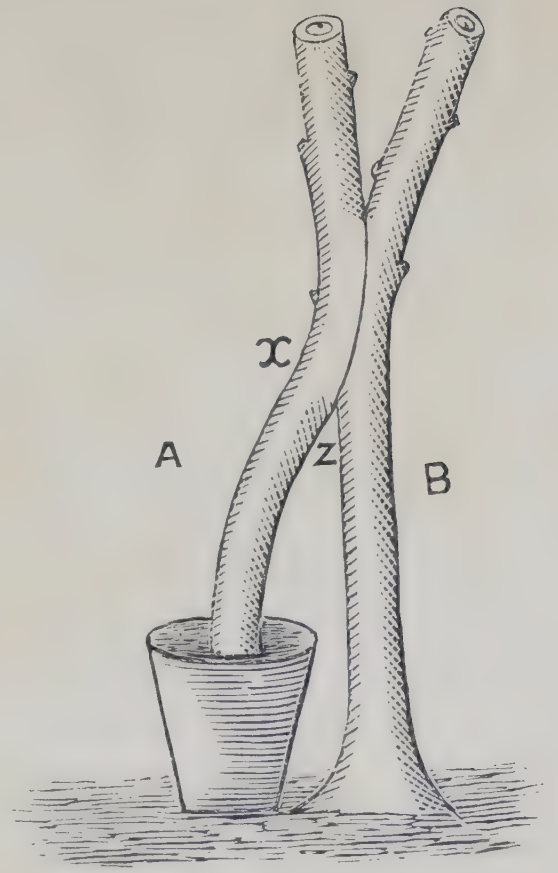


FIG. 3.
GRAFTING BY APPROACH OR INARCHING.

the former have lost their silky appearance and taken on the deep green tint. Such a method obviates loss in time as the graft is established at an early stage of the stock's life. When the grafting is done by inarching or approach it is very conveniently carried out when both scion and stock are in the seedling state. Grafting by methods other than the "approach" can be performed when the trees have been planted and are several years old.

Budding Cacao.

Budding of cacao usually consists of removing a piece of bark with a bud from one tree yielding a good variety of cacao, and bringing it into close contact with another plant of quick growth from which a corresponding piece of bark has been removed. When the operation is being performed the stock and the tree from which the buds are taken should be growing rapidly; the stock and bud-wood should be from $\frac{3}{4}$ to $1\frac{1}{2}$ inches in diameter. The same precautions regarding moisture and aëration should be observed in budding as in grafting, and the bud tied very firmly on to the stock.

Budding cacao has met with considerable success in Jamaica; it not only gives an even quality of cacao from all trees successfully experimented with, but it allows one to improve the bearing capacity of the trees by budding good cropping varieties on to quick-growing shoots of inferior cropping varieties. According to Harris* the new budded plants should be in bearing within a year.

In Jamaica it has been recommended to select the best bearing trees; these should have their pods and primary branches removed, and should be manured heavily to induce them to produce as many vertical shoots (gormandisers or suckers) as possible to be used as bud-wood; then cut down to within a foot or so from the ground all poor trees and train up two suckers, one for budding upon and the other to be cut down when the bud is firmly established as the stem of the new tree.

An important point has been brought forward in connection with the vegetative methods of improving the yield and quality of cacao, with special reference to budding. It is commonly accepted that the vegetative system of the Caracas or Criollo variety is weaker than that of the Calabacillo, Amelonado, or other Forastero types; this specially applies to the root system, and it has been argued that the Caracas trees, though they cannot withstand strong winds when supported by their own root system ,may do so when grafted or budded on to varieties with stronger root systems. According to one report † "Harris brought some bud-wood of Criollo and worked the buds on stocks of Forastero and Calabacillo that had previously been prepared; these are growing out in the full sun, and three months after budding are three feet high and are beginning to branch at the top". This is an interesting result, and experiments in the same direction are well worth trying.

* T. J. Harris. Bulletin of Dep. of Agr., Jamaica, November, 1903.

† Annual Report. Botanic Department. Jamaica. 1904.

CHAPTER IX.

HARVESTING, SHELLING, AND FERMENTING OF CACAO.

Harvesting and Shelling.

THE cacao fruits are collected when ripe, then shelled, and the seeds subsequently placed in the fermenting chamber. They are considered ripe when the whole of the fruit wall has changed to the characteristic colour—yellow or reddish-yellow: fruits with any part of their walls tinted green are usually considered to be unripe, and are allowed to remain on the tree until the colour-change is complete. It is obvious, however, that such a criterion indicates when the fruit wall itself is ripe, a condition often subsequent to that of the maturity of the enclosed seeds; nevertheless, some of the planters in Ceylon of long experience never allow the fruits to be collected until the tip or apex of the fruit—the last part of the wall to ripen—has changed colour. On the other hand, many cacao planters judge the ripeness of the seeds by tapping the walls of the fruit, experience enabling them to determine the degree of maturity by the sound; the seeds when ripe become loose inside the fruit, and a characteristic sound is produced when the walls of the latter are tapped with the finger. Generally, the characteristic sound indicates that the seeds are ripe; the colour of the wall on the other hand is occasionally misleading as, during those months of the year with hot days and cold nights, the fruit wall ripens very slowly, and when the change of colour is complete many of the seeds have often germinated within the unbroken fruit. Germination within the fruit is not, however, of such frequent occurrence as to constitute a strong argument against the practice of allowing the fruits to remain until the change of colour is complete; if it is correct that the latter system ensures evenness in size, reduction in the number of shrivelled cured beans, and improved plumpness of the seeds, it has much to recommend it.

In Trinidad there are two principal harvests in the year, one in May to June and the other in November to December, and smaller harvests during the rest of the year. There the planters distinguish the fruits of the trunk from those of the branches; preference is given to the harvests of the trunk because the pods ripen earlier, are large, and the individual seeds are said to be better nourished and larger.

In wet weather when the fungus attacking the cacao fruits is very prolific, it is advisable to collect the ripe fruits every week; and in any case "collecting frequently and collecting little"

is preferable to collecting all pods in various degrees of ripeness at intervals of every month.

Knives for Collecting Cacao.

The fruits on the lower parts of cacao trees can be reached by the average cooly, and cut by means of a small hand-pruning knife. For cutting or collecting cacao fruits on the higher parts of trees several forms of knives are used, usually supported on very long wooden handles. The essential points of such knives are (1) that they should make a clean cut without dragging; (2) that they can be used to cut one ripe fruit in a bunch of unripe ones; (3) the cutting parts should be capable of being sharpened easily; (4) the apparatus should be light in weight, but strong and durable; and (5) should be of such a length that any fruits, whatever their height, may be easily reached and cut by increasing the length of the handle; (6) the knives should allow the operator to cut clean, and leave the basal knob of peduncular tissue uninjured. According to Semler, on one cacao plantation in Central America, a movable platform or scaffolding was used to enable the operator to cut, by means of pruning shears, the cacao fruits on trees which by pruning are maintained at a height of four metres.

Shelling Cacao Fruits.

In Ceylon, the shelling or breaking is done either with a cut from a knife held in the hand or by pressing the fruit against a steel cutting surface lodged in a piece of wood; the latter can be carried about from one place to another. The breaking is usually done in the field or under covered sheds, and the seeds are then separated from the stringy placenta and accumulated in baskets. It is only necessary to obviate cutting or pressing of the seeds and their admixture with pieces of placenta, fruit wall, soil, etc. The fruit walls are generally buried in pits, earth and lime being used to cover them, or they are burnt or crushed to form manure.

Though the cost of harvesting is considerably increased by transporting the picked fruits to a central covered shed, the practice has much to recommend it, as the shelling is done without exposure to rain; there is also less likelihood of introducing foreign matter among the seeds, and the fruits can be selected and grouped according to the varieties to which they belong. If the fruits are not grouped into varieties there cannot be an even fermentation of the seeds, as the seeds from Amelonado, Criollo, Cundeamor, Nicaraguan and other varieties are mixed in the same heap.

When the fresh seeds have been accumulated in sufficiently large quantities and all undesirable matters removed, they are placed in tanks or other receptacles in order to allow them to ferment.

Fermentation: Object of the Process.

Briefly stated the object of fermenting cacao seeds is to remove the sugary pulp surrounding them, to promote chemical changes

within the kernels of the seeds; to convert the bitter astringent taste into a sweet one, and to improve their colour, fracture, and flavour. Such changes are brought about when large numbers of seeds, fresh from the fruit, are heaped together and allowed to remain in contact with one another. Though the process involves a relative high temperature it is very rare that the latter destroys the embryo of the seed; to a certain extent fermentation is a continuation of the processes commenced in the seeds after maturity. Ordinarily fermented seeds, if dried under unfavourable conditions, will germinate, the prevention of such developments being one of the main objects of curing; this proves that the fermenting of cacao does not involve chemical changes harmful to the vitality of the seeds.

The necessity of, and improvement in quality effected by, the ordinary fermentation of cacao are generally acknowledged; nevertheless, some countries do as little fermenting as possible, and in some places this operation is entirely neglected. According to some authorities the purple colour and bitter taste of the unfermented dried seeds are wanted by some markets.

In 1902, several experiments were made at the Experiment Station, Peradeniya, with the object of effecting a good curing of seeds which had been fermented inside the fruit. In the first experiment the fruits were exposed to the sun for seven days until their walls were brown and brittle; the seeds were then cured in the sun, some after washing, others without washing. The cured seed prepared in this manner was dark in colour externally; internally it was very uneven in colour and not at all brittle. In a second experiment the fresh unbroken fruits were placed in a curing house, and kept at a temperature of about 100° F. for three days. The beans fermented under such conditions were subsequently cured in the sun as in the first experiment, and with very nearly the same results. In a third experiment fresh seeds were exposed to the sun without any fermenting, but with poor results.

In none of these experiments did the results obtained justify the change in our method of fermenting. All the seeds which were fermented inside the fruit, or cured without being fermented, had to be placed along with the "black" cacao, owing to the pliable nature and uneven colour of the substance of the seed.

Fermentation and Bacteria.

The changes effected during fermentation are dependent upon the activity of living organisms, and by a study of the life-histories of the latter and by determining the conditions of temperature, moisture, and aëration necessary for their development much valuable knowledge may be obtained. In most processes of fermentation the "yeast" organisms are concerned, and in this respect cacao is no exception. Preyer*, who worked at this subject in Ceylon, states that *Saccharomyces Theobromæ* effects the best fermentation, but that *S. cerevisiæ* and a species resembling *S*

* Dr. Preyer, Der Tropenpflanzer, April, 1901.

ellipsoidies and *S. membranæfacieus*, as well as *Penicilium*, have been observed by him in fermenting cacao.

It is generally conceded that the best fermentation is effected by maintaining an equal temperature or bacterial activity throughout the cacao in the sweating tanks, but opinion appears to be divided on the question of retaining or allowing the sweatings to escape.

Preyer succeeded in breeding pure cultures of the organisms concerned in the fermenting of cacao, and by inoculation it is obvious that the various changes may be accelerated or retarded according to the objects in view. The elimination of the bacteria necessary for the production of undesirable quantities of organic acids is engaging the attention of many persons, and before long some satisfactory data may be in our possession which will allow us to more effectively control the changes in the flavour and colour of the fermented seeds. The methods employed in different countries vary considerably, especially with reference to the temperature during the period of fermentation; these differences can be associated with definite chemical and bacterial changes.

Methods of Fermenting.

It is now necessary to describe the various methods of fermenting adopted in different cacao-growing countries. In Ceylon most cacao planters adopt what may be termed the natural method of fermenting, which consists in heaping the fresh seeds on the floor or in receptacles and covering them with leaves of the banana, or ordinary cloth, or layers of these alternating with layers of earth. The fermenting floor is usually built with a slope, so that the watery products may escape during fermentation. Each heap may consist of four or more bushels of fresh seeds, which are turned over every day to prevent the temperature rising too high, and to ensure an uniform product; a period of thirty-six hours to five days or even longer is allowed for fermentation according to the variety dealt with and the circulation of air maintained through the heated mass, after which the seeds are washed and then cured, either in the sun or in rooms supplied with hot air.

The cacao planters in Ceylon do not usually separate the different varieties from one another, but more often than not ferment the seeds from fruits of the Caracas, Forastero, and Amelonado varieties in the same heap. The only selection usually made is in fermenting seeds from unripe or diseased fruits in special heaps; these are never fermented in the same heaps as the seeds from healthy mature pods. When the fruits are divided into classes comprising (1) mature healthy fruits; (2) immature healthy fruits and (3) diseased fruits, and each fermented in separate heaps there is a slight advantage, but it is much more important to separate the first group into its component varieties. If all the varieties are fermented in one heap, the fermentation is very uneven, and the final product cannot be uniform in quality.

On some estates the coolies are trained to detect, in the freshly-fermented and washed material, the purple seeds of the Forastero and Amelonado fruits from the white seeds of the Caracas variety, the former having much thicker integuments than the latter and appearing darker in colour; the colour of the kernel can, to some extent, be distinguished through the integument in the freshly-washed seeds. This allows one to obtain uniform samples of cured cacao, but it does not obviate the uneven fermentation.

The rapidity of fermentation depends to some extent on the thickness of the seed integuments; the Nicaraguan and Caracas seeds have very thin integuments, and fermentation is consequently effected much more rapidly than in the thicker-skinned seeds of the Amelonado, Calabacillo, or Forastero varieties. The thick-skinned, flat, bitter, and purple seeds of Amelonado fruits require a longer period for fermentation than any other kind cultivated in Ceylon, and it appears to be erroneous to ferment all varieties in the same heap.

In addition to the ordinary or natural fermentation of cacao, other methods have been brought forward, which are dependent upon maintaining the fermenting heap of seeds at a constant temperature. At the Experiment Station, Peradeniya, a series of tanks, lined with cement, has been made; on two sides of each tank are a large number of holes with an average diameter of 7.5 c.m. (3 inches); through each hole a perforated bamboo is pushed, the latter being of such a length as to stretch from one side of the tank to the other. By this means air can be let into or drawn through the fermenting heap according to requirements; the floor is made with a slope to one point, where a perforated sieve is placed, to allow the watery products of fermentation to escape.

M. Schulte* has devised a fermenter which allows the operator to maintain the fresh cacao seeds at a constant temperature of 60°C. In this method the cacao is placed in specially made wood receptacles, positioned one above the other, and each made to carry six or more frames between which air spaces exist. The fresh seeds are arranged to a depth of 10 cm. on the frames, and these are then put into the fermenter. The fermenter consists of two chambers fitting tightly together, and is maintained at a temperature of 60°C. by conducting channels which allow the hot air to circulate from grates disposed at one end of the apparatus. Thermometers indicate when it is necessary to increase or decrease the temperature. It is asserted that by such an apparatus the cacao is fermented in such a manner as to produce a homogenous product, and one which is freer from acidity than most of the cacao placed on the market. M. Maurice Montet in his criticism on the apparatus and method designed by M. Schulte, states that though the results ascribed to this process are possible, the

* Journal D' Agriculture Tropicale, No. 52, October 31, 1905.

cost of the apparatus and labour, and the skilled assistance necessary to supervise the work are such as to make the process of little value to cacao planters in most parts of the tropics. Furthermore, it has been pointed out that the cacao on the public market is often classed and valued more according to the countries from which it has been obtained than the method of fermentation adopted; this, though correct to a certain degree, should not discourage the introduction of new and better methods of fermenting, as it is obvious from the present range in value of cacao from any one country that better qualities will ultimately receive recognition.

Fermenting in Tropical America.

The time taken to effect a good fermentation in parts of Central America varies according to the variety dealt with and the methods adopted. In Nicaragua the seeds from Criollo and Lagarto fruits are fermented for two days and the Trinitario seeds about four to five days; in Salvador the seeds are usually fermented for one or two days, and the same length of time appears to be allowed for the varieties in Guatemala.

Fermenting in Surinam, Venezuela, Mexico, etc.

Preuss is of the opinion that the cacao varieties grown in Cameroon are not inferior to those cultivated in Surinam, though the cacao exported from the latter place is the better one. He attributes the bitter taste and sour smell of much of the Cameroon cacao to the want of efficient fermenting, and ascribes the good qualities of the cacao from Surinam to the systematic fermenting which is adopted. The fermenting chambers in Surinam consist of series of compartments, often eight in a series, and some measuring 1·5 metres in breadth, 2·25 m. in depth and 1·7 m. in height; these chambers are made of wood, provided with intervening air spaces and are constructed with sloping floors.

In fermenting, one box or chamber is left empty; the others are filled with wet cacao, often to a depth of one metre, and the cacao is covered with banana leaves, and the box is then closed. The cacao is allowed to ferment in this condition for one day, when that from the chamber next to the empty one is transferred to the latter; the contents of each box, after each empty one has been well washed, are transferred to the next empty one, and by this means the cacao is well mixed and superfluous sweatings removed. Each box is again allowed to retain the fermenting cacao for one day, when the same process is again gone through; at the end of 5 to 8 days, fermentation is usually considered complete, though only long experience can teach those responsible when the desired changes have been induced.

In Surinam a temperature above 45° C. is considered to be detrimental, and all fermenting chambers are situated in places protected from the wind. The sweatings are, by means of the sloping floor, conducted to an open channel constructed of glazed earthenware, and are thus allowed to escape from the fermenting

heaps of cacao. The best results are believed to be obtained by fermenting large instead of small quantities of cacao; the Surinam planters believe that the changes are more complete and better when fermenting is done in moist than in wet weather.

According to Chittenden in Venezuela*, "the conuquero puts his beans to drain, and forthwith exposes them to the sun for say five or six hours, then heaps and packs them up to sweat afresh until the following day, when they get five or six hours more sun and so on. Another contrivance of the small grower is that of bagging the cacao at the end of the day whilst still hot from exposure to the sun and allowing it to sweat during the night."

In Mexico, according to one authority, holes are made in the earth and lined with sacks or leaves of bananas; in these the seeds are placed and then covered with sacks or leaves; the material is then left till the cacao is sufficiently fermented. In Surinam, according to the same authority, the cacao is thrown into heaps in wooden sheds and covered with banana leaves.

In certain countries of South America the seeds are put into leather bags to ferment, and left suspended till the changes are complete; large casks are often used in which the fermented cacao is placed, and the casks rolled to aid in the mixing of the fermented mass. In Grenada and Trinidad, according to Van der Held, the Strickland method is employed; this requires a transference to three separate receptacles for different fermentations, the fermentation often requiring twelve days.

Fermenting in Java.

In the opinion of Van der Held†, after his experiences in Java, the cacao ferments best in receptacles of wood with the minimum quantity of air. It is not absolutely necessary that these should be constructed of closed walls, but they should be capable of being covered and should be situated in places sheltered from the wind. In Java the fermentation is sometimes made in movable receptacles, the wooden walls of which are perforated in order to allow the by-products of fermentation to flow away; in the same island sometimes fixed receptacles of large dimensions are used. If the production of cacao is not very considerable, Van der Held recommends the use of small movable receptacles which can be easily cleaned. For a large estate he recommends the following:—Place the fermenting tubs or troughs in an amphitheatre, and have the walls made of movable planks capable of being slided into the grooves of supports. Each receptacle is two metres long, one broad, and one deep, and is capable of holding ten piculs of fresh seeds. They should be arranged in such a manner as to be on the same level, in a row, and their number increased according to requirements. When the seeds have been ten to twelve hours in the upper trough they are transferred to the trough beneath, this being easily done on account of the movable planks forming the walls. When the cacao in the upper chamber is

* Cacao, by J. Hinchley Hart. Trinidad, 1900. † Van der Held, l.c.

to be put below, it is only necessary to raise the partition. Van der Held obtained the best results by changing the receptacles twice a day in order to avoid heating; this was done between 7 and 8 in the morning and 4 and 5 in the afternoon. The bottom of the chambers is perforated, the openings being about half-a-centimetre in diameter: these allow the liquid to flow away. A gutter is fixed to the floor to conduct the liquid to a central point should it be required for vinegar production.

Fermenting in the West Indies.

In the Jamaica Bulletin for August, 1900, the following proces is described:—"Accumulate at least 500 pods before breaking; you will get better results by having larger quantities. A simple box is made one foot deep and varying in length and width according to the quantity of cacao; the contents of 1,000 pods require a box 2ft. 6 in. long, 2ft. wide and 1ft. deep (inside measurements) and will fill such a box to a depth of 9 inches. It must be constructed so that no iron nails come in contact with the cacao, for iron is attacked by the "sweatings" forming a black liquor which discolours the cacao. The bottom of the box is bored with numerous holes, and is raised from the ground on two blocks of wood. It should be under cover and in a clean place free from dust: no lid is required. After filling with cacao, cover with a piece of clean sacking. Each morning turn up the whole mass with the hands; the cacao which was at the side and bottom being now towards the centre. If the quantity is small, turn out to dry on the fifth day, if larger (say over 2,000 pods) on the sixth day, i. e., after five full days' "sweating". Scrub out the box thoroughly, wash and dry the sacking before beginning a fresh batch. Thus by a short fermentation of a shallow mass, with plentiful access of air, you will get better results than by keeping the mass closely packed together in a deeper vessel. The close packing of the mass does not make it hotter; on the contrary the more air that reaches the mass, up to a certain limit, the hotter the cacao will become. As prices stand at present you will not find it advisable to ferment for a longer time, but on the other hand I cannot recommend you to shorten the time by a single day as your cacao would then retain too much of its original bitter flavour". This method is interesting, but whether it is largely adopted in Jamaica or elsewhere is not quite clear.

Fermenting Cacao in Trinidad.

The fermenting of the cacao in Trinidad is, according to Preuss, carried out on very much the same principle as in Surinam, though fermenting houses in the former place are frequently only protected by a roof to keep the rain off the boxes. Many methods are adopted in the island of Trinidad. One fermenting house on La Réunion Plantation, Trinidad, consists of sixteen compartments, each 1·5 metres high and about as broad, and 2 metres long. The walls are made of wood, and between every two boxes and along the sides is a layer of clay and dried grass, sometimes about 20 cm.

thick, to act as a non-conductor of heat; each compartment is supplied with a lid. The boxes are filled to a depth of about one metre with fresh wet cacao, covered with a layer of banana leaves and then closed. One box is kept empty so that the seeds can be transferred at any time and the used boxes washed out every day or two. The seeds are first fermented for one or two days, after which they are transferred to an empty box and fermented again for a similar period. The transference from box to box is made every one or two days until fermentation is complete, 8 days being generally required for ordinary Forastero seeds and 14 days for Calabacillo.

In some districts the cacao is fermented in bags suspended in holes in the earth, the contents being repeatedly kneaded without the sack being opened; by this means fermentation is said to be effected in about five days.

Another method is that associated with Cradwick, which consists of using a cask perforated at the bottom to allow the liquid to escape; the floor is covered with a thick layer of dried banana leaves (25 cm. in thickness), and the walls are covered with a layer of the same material. The wet seeds are placed in the cask, and then covered with banana leaves and allowed to ferment; after they have fermented for about two days, those in the upper part are taken out separately and subsequently returned first to the empty cask so as to be at the bottom during the following days, and those which were previously at the bottom now occupy the upper part. This operation is again repeated after two days' fermenting. This method is said to be suitable for fermenting cacao from about a thousand fruits, but if more are used an undesirable temperature may occur; if the quantity is less, more banana leaves are used and the cacao often weighted during fermentation.

Fermentation in Africa.

The report * of one company operating in Africa states that in the preparation of cacao very good results have been obtained by fermenting it for six days, the cured product having lost much of its bitter taste and secured a higher valuation. The same persons also report that the washing of cacao, though it always gave them a clear bright colour, has now been dispensed with as, by omitting this operation, they thereby increase their weight of cacao by 8 to 10 per cent.

In West Africa, according to Johnson, the old plan of preparing the beans for market by simply drying them in the sun has been abandoned in favour of the fermenting method introduced by the Government Botanic Department. "The beans are now placed in heaps upon mats, and then covered up with mats weighed down with stones, and left for four days if this takes place upon the same day the pods are plucked, but for three days if upon the following day; after which they are washed in baskets"

* Kamerun Land-und Plantagen-Gesellschaft, Hamburg, p. 481, Der Tropenpflanzer, November, 1902.

Various fermentation experiments have been made with the purple and bitter seeds of varieties cultivated in Cameroon, and reports have been issued which are, to a certain extent, somewhat contradictory. One authority * asserts that by fermenting the seeds in a particular manner it is possible to almost entirely remove the bitter, unpleasant taste so frequent in purple seeds fermented in the ordinary manner.

Length of Fermentation.

Though the fermentation process is considered to be of vital importance in the production of good kinds of cacao, there is a very conspicuous variation in the time allowed for it, and most people calculate when it is complete by the appearance of the material to the naked eye and the odour of the mass of seeds. Cacao is sometimes only fermented for two days, at other times the changes are allowed to continue for twelve or even more days, and in all cases cacao of good quality is apparently produced. It may, however, be considered safe to state that those varieties having thin integuments and white cotyledons require the minimum time, and those with thicker integuments and purple cotyledons the maximum; to the former class belong the Caracas, Nicaraguan, and some forms of Forastero, and to the latter the Calabacillo, Amelonado, and inferior kinds of Forastero.

The length of time required can only be determined by practice, as the chemical and physical characters of the seeds of the same variety vary according to the plant, its diseases, and to some extent climatic conditions. It is asserted that the pulp which surrounds the seeds contains, in Java, more water during the west monsoon than in the east monsoon, and that in wet weather the fermentation takes place more rapidly. The time required will also vary according to the method employed, the market for which the cacao is being prepared, and the quantity being fermented. Large quantities of cacao ferment quicker than small quantities, and due allowance must be made for this.

In parts of Java † the cacao from diseased trees is allowed to ferment two nights and sometimes even only one on account of its condition. After a night of fermentation the seeds from diseased specimens may germinate and produce cacao which is for the most part broken, very light, and of bad quality. Usually healthy cacao is allowed to ferment three days.

The Criollo or Caracas type in Java, Ceylon, and Trinidad does not, as a rule, require more than two days though it is often fermented for five; the Forastero a day longer and the Amelonado four or five days. Preuss states that the finest and sweetest cacaos require 24 hours and the bitter kinds 6 to 8 days. Fermentation is considered complete when, on cutting a seed transversely, one notices that the cotyledons have separated and the sugary liquid occupies the spaces within the seed. On

* Zur Kakao-Fermentation, by Dr. A. Schulte im Hofe, Der Tropenpflanzer, May, 1901.

† Van der Held, l. c.

drying, the beans may be brown in colour and sweet to the taste, or purple coloured and bitter to the taste, the former being the desired characteristics on most European markets.

Temperature During Fermentation.

The temperature to which a fermenting heap of cacao will rise depends to some extent on the quantity of seeds, the development of specific organisms, and the amount of air allowed to circulate through the mass of material. In most cases no record of temperature is kept, the quantity of cacao in each heap or box is not constant, and air is, as far as possible excluded, except when the fermenting materials are turned over to prevent the temperature rising too high. Hart has shown that as far as break and colour of the kernels are concerned, a temperature above 80° F. is really not necessary, and though his results were obtained by peeling off the integuments and putting the skinned kernels and the pulp together for three days—a method not advisable in the preparation of cacao—they proved an interesting point regarding the importance of temperature alone in the production of two essential characters of cured cacao.

Fermentation and Temperature.

Preyer* tabulates the temperatures associated with various systems of fermenting in Ceylon, the West Indies, and Cameroon ; these are given below, together with later results, and should be compared with those detailed elsewhere :—

	Method of Fermentation.	Temperature employed.
Preyer ...	Heaping method (Ceylon)	
	In the upper half ...	30-40°C
	In the lower half ...	Outside temperature to [30° C.
Chittenden ...	Some samples fermented well at ...	80° F=26. 70° C.
,, ...	With the method in vogue in Trinidad. ...	46-49° C=(115 to 120°F.)
Morris ...	By the method practised in the West Indies ...	About 140° F.=60° C.
Strickland ...	Three tank system (West Indies) In tank 1 ...	Not over 115-120° F. =46-49° C.
	In tank 2 ...	Not under 95° F.=35° C.
	In tank 3 ...	Do.
Friederici ...	Three tank system (Cameroon) In tank 1 ...	30-33° C.
	,, ,, 2 ...	35-38° C.
	,, ,, 3 ...	Not over 43-45° C.
Preuss ...	3 tank system (Surinam) ...	Never above 45° C.
Wright ...	3 tank system (Ceylon)	
	Tank 1 ...	25 to 30° C.
	Tank 2 ...	30 to 40° C.
	Tank 3 ...	33 to 44° C.
Johnson ...	Heaping method (Gold Coast) ...	Below 60° C.

* Dr. Axel Preyer, Über Kakao fermentation, p. 6.

Observations at Peradeniya.

In Ceylon the wet cacao is heaped in a particular manner, and during fermentation is turned over once every twelve or twenty-four hours; there is rarely any attempt made to keep the cacao at a constant temperature by hourly stirring the seeds, regulating the air inlet or the escape of the sweatings. The changes in temperature in cacao heaps thus fermented depend upon many factors, but mainly upon the quantity of wet cacao, the variety, and the length of the fermenting period. The following tabulated observations will perhaps serve to make these matters clear:—

Variety.	Weight of wet Cacao.	Range in temperature.	Length of fermenting period
	lb.	°C.	Hours.
Caracas ...	416	25 to 43·3	37½
Caracas ...	19	26 to 29·4	39
Forastero ...	543	25 to 44·1	61½
Forastero ...	307	26 to 32·9	63
Amelonado ...	203	25 to 40·1	85½
Amelonado ...	101	26 to 33·5	87
Mixed ...	250	26·8 to 28·8	39
Do. ...	250	26·8 to 30·8	63
Do. ...	250	26·8 to 33·7	87
Do. ...	300	27·0 to 30·5	39

The relationship between the temperature and quantity of cacao fermented appears to be a definite one; dissimilar quantities of Caracas cacao fermented for approximately the same periods show a difference of about 14° C. for a difference of about 400 lb. of cacao; similarly with Forastero cacao there is a difference in temperature of about 12° C. for a difference of about 230 lb. of cacao; in Amelonado a difference of about 6·5° C. for a difference of 100 lb. of cacao. In all the above cases the larger quantities of cacao are, in the ordinary process of fermentation, subject to a much higher temperature than smaller quantities, though these differences do not appear to be always traceable in the appearance and general physical properties of the cured beans.

The rise in temperature of the same mass of fermenting cacao, during each day, is manifest; generally the temperature rises 3 to 8° C. during every 24 hours, though, as will be seen from the following tables, there is considerable variation in this respect. The difference between the temperature of the air and that of the

fermenting seeds is very variable as is obvious from the following details :—

TABLE SHOWING COMPLETE RANGES IN TEMPERATURE :

FERMENTING TEMPERATURES IN °C.

Forastero, Caracas, and Amelonado Fermented Separately.

Date.	Time.	Temp. of Air.	Forastero (1.)		Caracas (2.)		Amelonado (3.)	
			Cacao.	Diff.	Cacao.	Diff.	Cacao.	Diff.
		°c.	°c.	°c.	°c.	°c.	°c.	°c.
29-6-06.	6 p.m.	25·0	25·0	0·0	25·0	0·0	25·0	0·0
,,	7 ,,	25·1	25·4	0·3	25·1	0·0	25·2	0·1
30-6-06.	6 a.m.	20·2	25·3	5·1	30·1	9·9	30·0	9·8
,,	7 ,,	20·4	25·4	5·0	30·1	9·7	30·3	9·9
,,	11 ,,	20·3	30·0	9·7	30·4	10·1	30·2	9·9
,,	12 ,,	20·4	30·0	9·6	30·4	10·0	30·2	9·8
,,	1 p.m.	20·4	30·1	9·7	30·4	10·0	30·2	9·8
,,	4 ,,	30·0	30·1	0·1	35·0	5·0	30·3	0·3
,,	5 ,,	25·3	30·1	4·8	30·4	5·1	30·3	5·0
,,	6 ,,	25·3	30·2	4·9	30·4	5·1	30·2	4·9
,,	7 ,,	25·4	30·1	4·7	35·0	9·6	30·3	4·9
1-7-06.	6 a.m.	20·4	30·1	9·7	35·2	14·8	30·3	9·9
,,	7 ,,	25·0	30·2	5·2	35·2	10·2	34·2	9·2
,,	8 ,,	25·1	30·2	5·1			35·3	10·2
,,	9 ,,	25·1	30·2	5·1			35·3	10·2
,,	10 ,,	25·2	30·2	5·0			35·2	10·0
,,	11 ,,	25 2	30·3	5·1			35·2	10·0
,,	12 ,,	25·4	30·3	4·9			35·3	9·9
,,	1 p.m.	25·2	30·3	5·1			35·2	10·0
,,	2 ,,	24·3	30·3	6·0			34·4	10·1
,,	3 ,,	24·3	30·2	5·9			34·4	10·1
,,	4 ,,	24·2	30·1	5·9			34·3	10·1
,,	5 ,,	24·3	30·1	5·8			34·2	9·9
,,	6 ,,	24·3	30·3	6·0			34·2	9·9
,,	7 ,,	25·0	30·2	5·2			35·0	10·0
2-7-06.	6 a.m.	20·3	35·1	14·8			40·0	19·7
,,	7 ,,	20·3	35·1	14·8			40·0	19·7
,,	11 ,,	25·2					40·0	14·8
,,	12 ,,	25·2					40·0	14·8
,,	1 p.m.	25·2					40·0	14·8
,,	2 ,,	25·3					40·1	14·8
,,	3 ,,	25·3					40·1	14·8
,,	4 ,,	25·4					40·1	14·7
,,	5 ,,	25·3					40·0	14·7
,,	6 ,,	25·1					35·4	10·3
,,	7 ,,	25·2					35.4	10·2
3-7-06.	6 a.m.	20·4					40·1	19·7
,,	7 ,,	20·4					40·1	19·7

Forastero removed from tank after 61 hours' fermentation.

Caracas removed from tank after 37 hour's fermentation.

Amelonado removed after 85 hours' fermentation.

The following were the temperatures for other separate heaps of cacao (abbreviated to show the differences more prominently):—

TABLE SHOWING RANGE IN TEMPERATURE.

Date.	Time.	Fermenting Temperatures in °C.						
		Temperature of Air.	Forastero (1)		Caracas (2)		Amelonado (3)	
			Cacao.	Diff.	Cacao.	Diff.	Cacao.	Diff.
		°C.	°C.	°C.	°C.	°C	°C	°C.
25-6-06	3 P.M.	30·1	30·1	0.0	30·1	0·0	30·1	0·0
26-6-06	6 A.M.	25·1	34·0	8·9	33·3	8·2	26·1	1·0
,,	10 ,,	25·4	29·0	3·6	38·0	12·6	28·2	2·8
,,	2 P.M.	30·1	34·0	3.9	38·1	8·0	33·0	2·9
,,	6 ,,	30·0	34·4	4·4	38·3	8·3	33·2	3·2
27-6-06	6 A.M.	20·4	39·2	18·8	38·4	18·0	33·2	12·8
,,	10 ,,	25·1	44·0	18·9			33·2	8·1
,,	2 P.M.	25·3	43·9	18·6			32·2	6·9
,,	6 ,,	25·3	44·0	18·7			33·2	7·9
28-6-06	6 A.M.	20·4	39·3	18·9			33·1	12·7
,,	10 ,,	21·0					33·3	12·3
,,	2 P.M.	23·5					33·4	9·9
,,	6 ,,	25·1					33·3	8·2
29-6-06	6 A.M.	20·3					38·1	17·8

These tables show the temperatures of the Caracas, Forastero, and Amelonado varieties when fermented in separate heaps, for periods of time according to their requirements. In the following table the temperatures are given for a fermenting heap comprised of all three varieties of cacao:—

FERMENTING EXPERIMENTS WITH MIXED SEEDS.

Date.	Time.	Fermenting seeds.	Air Temperature.	Difference.
	°C.	°C.	°C.	°C.
12.6.06 ...	4 P.M.	27·8	27·8	0
	5 ,,	28·5	24·0	4·5
	8 ,,	27·0	21·0	6·0
13.6.06 ...	6 A.M.	27·0	19·8	7·2
	7 ,,	28·0	19·9	8·1
	8 ,,	28·0	21·0	7·0
	9 ,,	28·4	21·4	7·0
	11 ,,	28·4	22·1	6·3
	12 ,,	28·6	22·3	6·3
	2 P.M.	29·0	21·6	7·4
	3 ,,	29·1	21·1	8·0
	4 ,,	29·2	21·2	8·0
	5 ,,	29·2	21·0	8·2
14.6.06 ...	7 A.M.	30·5	20·4	10·1

In the foregoing experiments only small quantities of cacao were dealt with, but the recorded range in temperature in fermenting heaps of cacao of different varieties during the same

period is of considerable interest; in all cases the final product was of fair quality. The Caracas seeds were fermented for 37 to 38 hours, Forastero 61 to 62 hours, the Amelonado 85 to 86 hours, and the mixed seeds 39 hours; the range in temperature in each group being respectively 25 to 38.4° C., 25 to 44° C., 25 to 40.1° C., and 27 to 30.5° C. The average difference between the temperature of the fermenting heaps and the air for the whole of the periods is given in the three tables.

Changes During Fermenation.

According to Harrison, Hart, Schulte, and others, as soon as the seeds are separated from the fruits and heaped together there commences in the sugary and soft part of the seeds an alcoholic fermentation, and at the same time an increase of temperature occurs. During this time a part of the sugary juice flows away from the heap; this may be collected for other purposes. In about twenty-four hours there is developed, besides the alcoholic, an acetic fermentation acetic acid is formed in large quantities, while at the same time the temperature rises still higher. If the temperature rises to a certain degree, there occurs at the same time as the acetic fermentation a butyrique fermentation which is said to exert a very unfavorable influence on the taste of the cacao; in order to avoid this it is recommended that the temperature be kept below 42° C.: a higher temperature favouring the butyrique fermentation. According to Preyer (Tropenpflanzer, April, 1901) the alcoholic fermentation is most active, and he asserts that it is not necessary to cover the seeds for the fermentation to be effected, a view not generally put into practice by cultivators.

Physical and Chemical Changes.

The physical and chemical changes brought about by fermentation are many, and it is necessary to deal separately with the pulp around the seeds, the integuments, kernels, and the total loss in weight.

Changes in the Pulp.

The watery white pulp of the fresh seeds is converted, by fermentation, into a more condensed, slimy, discoloured, and granular snbstance, which can be easily removed by washing, and which allows the seeds to be more rapidly dried. It is believed that the fermenting pulp is to some extent absorbed by the substance of the seed. Hart states that "unless we can stew the bean in its own juice, or absorb the constituents of the pulp through the membranous covering in some manner, we shall never properly ferment cacao or change the character of the interior of the bean." According to Harrison the sugars in the pulp undergo an alcoholic and acetic fermentation, and the liquid flowing from the fermenting heap contains, besides its own decomposition products, varying proportions of the materials of the kernels which are lost during fermentation;

it contains "the missing soluble constituents or the soluble products of their alteration and of that of the less soluble carbohydrates." The following table, given by Harrison, in Hart's book, shows the nature and proportion of the constituents in the ordinary liquid issuing from a fermenting heap of cacao:—

Composition of the Sweatings from a Mixture of Seeds from Calabacillo and Forastero Fruits.

Water	84·817
1. Albuminoids	·062
2. Indeterminate nitrogenous matters ...	·250
Glucose	11·604
Sucrose	·638
Astringent matter, etc.	·354
Alcohol	·180
Tartaric acid, free	·340
Acetic acid, free	·892
Acetic acid, combined	·290
Iron Peroxide	·038
Magnesia...	·074
Lime	·029
Potash	·354
Soda	·004
Sulphuric anhydride...	·021
Phosphoric anhydride	·038
Chlorine	·007
	100·000
1. Containing nitrogen	·010
2. ,, ,, ...	·040

Changes in the Integument.

The physical change induced in the skin of the seed consists of a conversion of the pale brown, moist covering into one of a deeper colour which when dry becomes reddish-brown and hard. The hard wall, if kept intact, protects the kernel; when too brittle it may break, and expose the substance of the seed to the air when subsequent deterioration becomes noticeable. If the fermentation and curing have been carried out too rapidly there is a tendency for the skin or integument of the seed to become loose; when this occurs it is almost impossible to avoid subsequent peeling of the covering and exposure of the cotyledons. When properly fermented and cured the integument is in close contact with the substance of the seed, but it can easily be removed if the beans are desired in the shelled condition. The outer surface is usually of a deeper brown than the inner; the striations run along the length of the bean, and are prominent on the outer surface but indistinguishable on the inner. The analyses of the shells of cacao by Harrison show that these integuments, whether dried or fermented and cured, contain most of the ingredients present in the kernels of the seeds; they are particularly rich in potash, phosphoric anhydride, and albuminoids, and must have a fair nutritive value.

The following are the analyses, given by Harrison,* of the cuticles or integuments of seeds of the Forastero and Calabacillo varieties :—

CUTICLES OF CACAO BEANS.

	Dried, Fermented, and Cured.			
	Forastero.		Calabacillo.	
	Dried.	Fermented and Cured.	Dried.	Fermented and Cured.
Water	11·840	11·840	12·400	12·400
1. Albuminoids ...	6·603	6·130	6·092	6·750
2. Indeterminate nitrogenous matters ...	traces	3·394	traces	4·006
3. Theobromine ...	1·808	·909	1·599	1·023
4. Caffeine	·306	·547	·272	·355
Fat	2·186	8·580	2·946	4·000
Glucose	5·200	·714	4·811	·476
Sucrose	·473	nil	·240	·143
Starch	6·779	3·682	6·271	4·865
Astringent matters ...	·561	4·350	2·621	2·113
Pectin, etc.	5·849	5·895	5·408	6·140
Cacao-red	3·662	3·100	3·391	3·000
Digestible fibre, etc. ...	34·100	31·292	36·388	35·721
Woody fibre	12·753	9·640	8·932	9·840
Tartaric acid, free ...	3·148	·420	2·913	·420
Acetic acid, free ...	traces	1·140	nil	·720
Tartaric acid, combined ...	1·823	3·456	2·010	3·450
Iron peroxide	·052	·218	·026	·057
Magnesia	·379	1·035	·756	·999
Lime..	·156	·224	·358	·266
Potash	1·288	2·038	1·260	1·821
Soda..	.078	·194	·272	·219
Silica.	.015	·250	·013	·200
Sulphuric anhydride ...	.161	·122	·139	·085
Phosphoric anhydride ...	.509	·807	·763	·912
Chlorine	.265	·023	·119	·019
	99·994	100·620	100·000	100·000
1. Containing Nitrogen ...	1·056	·981	·974	1·080
2. ,, ,, ...	trace	·543	traces	·640
3. ,, ,, ...	·544	·274	·492	·315
4. ,, ,, ...	·087	·155	.076	·099
Total Nitrogen ...	1·687	1·953	1·542	2·134

CHANGES IN THE KERNEL.

The changes in the character of the kernel are the most important to cacao planters. The kernel, in the fresh state, may be white (Caracas and Nicaraguan varieties) ; tinged with purple, (Forastero types) or deep purple (Amelonado variety); it contains a large proportion of water and is hard but not brittle ; it has a strong astringent taste, especially when from the deep purple-seeded varieties.

When fermented, the kernels are either slightly tinged brown or purple, and give way to the light or deep chocolate-brown colour when subsequently dried and cured; they lose a considerable amount of water, and on drying become brittle. In all cases proper

* Hart, l.c.

fermenting is accompanied by a conspicuous reduction in the percentage of astringent matters in the kernels, a change favourably affecting the flavour of the cured product.

The chemical changes which occur in the kernels during the process of fermentation are very complicated, and it is to Harrison, Jenman, and others in the West Indies that much of our knowledge on this subject is due. The changes result in great loss of some constituents and an increase of others; the chief gain appears to be in acetic acid—a product of fermentation.

The following analyses* by Harrison show the composition of the kernels of beans of Forastero and Calabacillo varieties, when ordinarily dried, and when fermented and cured :—

COMPOSITION OF THE KERNELS OF CALABACILLO AND FORASTERO VARIETIES.

	Dried, Fermented, and Cured.			
	Calabacillo.		Forastero.	
	Dried.	Fermented and Cured.	Dried.	Fermented and Cured.
Water	5·000	6·080	5·000	6·280
1. Albuminoids ...	10·202	7·310	7·228	6·130
2. Indeterminate nitrogenous matters ...	·809	3·406	4·081	2·525
3. Theobromine ...	2·059	1·659	1·321	1·480
4. Caffeine	·164	·058	·332	·414
Fat	44·574	48·400	45·831	52·120
Glucose	1·510	1·000	·247	·566
Sucrose	traces	nil	1·373	nil
Starch	5·735	5·329	9·043	6·750
Astringent matters ...	7·624	5·972	7·329	3·470
Pectin, etc.	1·586	1·950	2·068	·770
Cacao-red	4·497	2·300	2·311	2·850
Digestible fibre, etc. ...	7·287	6·182	3·969	5·762
Woody fibre	4·617	4·600	5·435	6·200
Tartaric acid, free ...	·120	·560	·057	·420
Acetic acid, free ...	nil	·900	nil	·600
Tartaric acid, combined ...	·726	·624	·729	·596
Iron peroxide	·048	·115	·048	·057
Magnesia	·493	·621	·680	·621
Lime..	·082	·196	·153	·154
Potash	1·283	·980	·951	·776
Soda..	·364	·477	·101	·196
Silica.	·024	·037	·024	·020
Sulphuric anhydride ...	·120	·051	·072	traces
Phosphoric anhydride ...	1·141	1·179	1·565	1·210
Chlorine	·028	·021	0·47	·043
	100·000	100·000	99·995	100·000
1. Containing nitrogen ...	1·662	1·170	1·156	·980
2. ,, ,, ...	·129	·545	·653	·404
3. ,, ,, ...	·634	·511	·406	·457
4. ,, ,, ...	·047	·014	·095	·119
Total Nitrogen ...	2·472	2·240	2·310	1·960

* Hart, l.c.

The chemical changes induced by fermenting and curing the seeds are dealt with as follows by Harrison :—" When the compositions of these substances are given in percentages it is difficult to perceive the changes in composition which may have taken place during the fermentation and curing. The results obtained have therefore been re-calculated on the assumption that the fat in the original beans as submitted to fermentation would undergo little or no change during the process ; comparison of the compositions of the portions of the fresh fruit submitted to fermentation and of the corresponding amount of the product yielded is thus approximately obtained. In the germination of the seeds the fat is used up as food for the plantlet, but in the process of fermentation and sweating, germination is so quickly checked that the more readily available sugars are not all absorbed or used up. Thence it is not likely that the fat will undergo appreciable change."

Loss during Fementation.

The proportion of the various ingredients* lost during the fermenting and curing processes is as follows :—

Losses Resulting From the Fermentation and Curing of a Mixture of Beans of "Calabacillo" and "Forastero".

Water	56·419
Albuminoids	·982
Indeterminate nitrogenous matters ...	·229
Theobromine	·159
Caffeine	Nil
Fat	Nil
Glucose	·301
Sucrose	·429
Starch	1·280
Astringent matters	1·258
Pectin	·518
Cacao-red	·270
Digestible fibre	1·167
Woody fibre	·518
Tartaric acid, free	·130
Acetic acid, free	·257
Tartaric acid, combined	·053
Iron peroxide	·010
Magnesia	·021
Lime	·004
Potash	·114
Soda	·002
Silica	·010
Sulphuric anhydride	·030
Phosphoric anhydride	·156
Chlorine	·022

From these results Harrison concludes that " there has occurred a loss in almost all constituents of the cacao, the only gains being in acetic acid, a product of the fermentation, and in iron peroxide and silica due to dirt and dust picked up during the final drying,"

The detailed analyses made by Harrison and others, and quoted by Hart, show the nature of the changes which occur during femen-

* Hart, l.c.

tation, and it is apparent that the total weights before and after fermentation must show considerable differences; the loss on fermentation is to a large extent unavoidable, but may be increased or decreased by adopting definite courses. The following extract will indicate the nature of the changes, and the consequent loss, during fermentation:—

"The results* of the examinations and analyses show that the process of fermentation or sweating of cacao consists in an alcoholic fermentation of the sugars in the pulp of the fruit accompanied by a loss of some of the albuminoid and indeterminate nitrogenous constituents of the beans. Probably the albuminoid constituents are first changed into amides and other simpler combinations which may be further broken up during the process of fermentation. Some parts of the carbohydrates other than sugars undergo hydrolysis, and either escape in the runnings from the boxes in the form of glucose, or undergo in turn the alcoholic and acetic fermentations. During this change some of the astringent matters to which the somewhat acrid taste of the raw beans is due are also hydrolysed, and thus a marked improvement in flavour is gained. Small quantities of the mineral constituents, principally of potash and phosphoric acid, are removed from the beans in the liquid escaping from the fermenting material. A slight loss in woody fibre is shown, which may be due to loss of portions of the cuticle during the operation of drying, or to changes in it by hydrolysis during fermentation."

Harrison further states that when seeds of the Forastero and Calabacillo varieties are similarly fermented and cured, those of the Forastero type lose a higher proportion of their weight than do those of the Calabacillo; the latter kind must, however, be fermented for a much longer period if the bitter taste and purple colour of the seeds are to be destroyed, and perhaps the total loss on fermenting and curing of Calabacillo will then be equal to or greater than that accompanying Forastero seeds.

Loss During Fermentation at Peradeniya.

Samples of different varieties were fermented for definite periods of time and the weights of the fresh, fermented, washed, and cured cacao taken at the respective stages. The following are some of the results obtained:—

Variety.	Period of fermentation.	Range of temperature during fermentation.	Weight of Cacao.		Loss on fermentation.
			Fresh.	Fermented.	
	Hours.		lb.	lb.	Per cent.
Caracas ...	37 to 38	25·0 to 43·3°C.	416	384	7·6
Forastero ...	61 to 62	25·0 to 44·1°C.	543	471	13·2
Amelonado	85 to 86	25·0 to 40·1	203	174	13·3
Mixed seeds	39	270 to 30·5	439	392	10·9

* Harrison, l. c.

In all such experiments account should be taken of the condition of the seeds when placed in the fermenting tanks. If the fruits are left on the tree for several days after reaching maturity, or are not shelled until many hours or a day after being taken from the tree, many changes take place, the pulpy matter around the seeds decreases in quantity, and the loss during fermentation is consequently much less than it would be under other conditions. It is very difficult to obtain all the fruits in an even condition of ripeness, or to calculate the loss of water which occurs while the seeds are being accumulated prior to being taken to the fermenting tanks; the proportionate loss of the different constituents, as given by Harrison, are therefore of much more value than those just dealt with.

In the Peradeniya experiments the loss recorded is probably the minimum, as no account was taken of changes subsequent to the seeds leaving the fermenting tanks, or of those which must occur in the time taken in transporting the fruits to a central place and accumulating the seeds in quantity. The results of these experiments showed that the maximum loss occurred in the Forastero and Amelonado seeds and the minimum in the Caracas, though much larger quantities should be investigated before attaching much weight to the proportionate losses which occurred in the experiments here recorded.

Relationship Between Loss in Weight to Length of Fermentation.

The relationship between the proportionate loss in weight and the length of the period of fermentation is clearly shown in these results; the Caracas, Mixed, Forastero, and Amelonado seeds were respectively fermented for longer periods, and the proportionate loss in these cases was 7·6, 10·9, 13·2 and 13·3 per cent. respectively. In another series of experiments the proportionate loss for the Caracas, Forastero, and Amelonado was 11·8, 15·8, and 16·4 per cent. respectively.

This is an important point to notice in comparing the relative values of the different varieties. Amelonado seeds must always be fermented for very long periods in order to eliminate the bitter taste and purple colour, and the loss in weight being in proportion to this, the value of the Amelonado variety is thereby lowered. Furthermore, the total loss in weight during fermenting, washing, and curing is proportionately larger with the Amelonado and Forastero than with the Caracas and other fine sorts.

The above experiments show the loss when each variety is fermented for periods of time in proportion to their requirements, and it may be argued that if the Caracas or Forastero types were fermented for the same length of time as the Amelonado they would show an equally large loss; this contention is probably correct, but at the same time it should be borne in mind that to ferment Caracas cacao, until the loss in weight equals that accompanying

an ordinary fermentation of Amelonado, would considerably damage the Caracas beans and lower their market value. The loss associated with the Amelonado seeds is, to a large extent, an unavoidable one.

The relation between the loss in weight and length of the fermenting period is shown not only when different varieties are fermented for respectively different periods, but when parts of the same mixture are fermented for different lengths of time. In the experiment outlined below, a batch of 750 lb. of wet cacao was divided into three equal parts; one was fermented for 39 hours and showed a loss of 15·6 per cent., the second lot for 63 hours with a loss of 17·8 per cent., and the third batch for 87 hours with a loss of 20·9 per cent.

Loss During Fermentation of Mixed Seeds.

Batch.	Period of fermentation	Range of temperature during fermentation.	Weight of Cacao.		Loss on fermentation.
			Fresh.	Fermented.	
	Hours.	°C.	lb.	lb. oz.	Per cent,
A. ...	39	26·8 to 28·8	250	210 10	15·6
B. ...	63	26·8 to 30·8	250	205 6	17.8
C. ...	87	26·8 to 33·7	250	197 10	20·9

Experiments in Africa.

Though it is obvious from the foregoing analyses and results that in the fermenting process there is a considerable loss in weight of important ingredients in the cacao seeds taken as a whole, opinion seems to be divided* as to whether the ultimate loss is seriously affected by a short or long period of fermentation. Some Trinidad cultivators maintain that there is no appreciable difference in the ultimate weight of cured cacao by reason of a short or long period of fermenting, while others believe that the highly fermented cacao loses more than that which is slightly fermented. Johnson† has made several experiments, and the following are some of his results :—

Batch No.	Period of Fermentation.	Mean Temperature for the Period.	Loss in weight during Fermentation.
I	8·5 days	119·13 degs. Fahr.	20·52 per cent.
II	12 ,,	95·77 ,, ,,	27·21 ,,
III	10·5 ,,	102·53 ,, ,,	26·08 ,,
IV	4·5 ,,	92·63 ,, ,,	11·42 ,,
V	6·5 ,,	106·99 ,, ,,	17·85 ,,
VI	7·5 ,,	112·73 ,, ,,	17·57 ,,

* Tropical Agriculturist, 1900-01, p. 133,
† Johnson, Annual Report, Gold Coast, 1904.

In these experiments it is clear that the loss bore a direct relationship to the length of the fermenting process, and if the longer fermentation is not accompanied by a better product it is not likely to be adopted. One batch, fermented for three days, was sold at the same price, in Hamburg, as another fermented for six days, the temperature never being allowed to exceed 60° C. during fermentation, and the cacao in both cases being washed before curing. It is interesting to record that the sample fermented for six days was reported upon as being "too blue in section and not fermented enough." These experiments prove conclusively that the loss is related to the length of the period of fermentation.

Fermentation in the Fruit.

It has often been questioned whether the cacao is not slightly fermented on the tree, or while within the fruits when the latter are accumulated for a day or more before being opened. The ordinary fermentation processes are not such as to destroy the vitality of the seeds, and when the latter are mature, they form, with the placentas, a mass of tissue not in contact with the wall of the fruit; it is therefore conceivable that if the fruits are left too long on the tree the placentas may form a disorganised mass, and fermentation to some extent take place before the fruits are collected. Fruits, in varying degrees of overripeness, show a reduction in the amount of the pulp around the seeds, and in many of the Caracas types the integuments of the seeds fresh from the fruits are perfectly brown; such seeds, though exclusively from overripe fruits, have occasionally been fermented to such an extent that they could be cured direct by washing and exposure to the sun. Fermenting changes take place in the seeds of overripe fruits and the fact that the seeds may, if left too long, subsequently germinate while within the fruits will prevent any cacao planter from imagining that fermentation may with advantage be allowed to take place before picking.

In some districts of Ceylon and in Trinidad,* the fruits are allowed to remain on the ground or are accumulated in the store houses for one or two days, and, according to Van der Held, this is done in Trinidad with the idea that the pulpy juices are partially absorbed and the seeds thereby increased in size. No matter what the object may be it is certain that, especially when the fruits have been bruised or broken in transit, a certain amount of fermentation will take place in two days; the changes will be very slow and almost negligible when the fruit walls are kept intact and air excluded.

* Sur la Preparation des Graines du Cacaoyer. by Van der Held; Revue des Cultures Coloniales, No. 124, May, 1903.

CHAPTER X.

WASHING, CURING, AND POLISHING OF CACAO.

When fermentation is completed the original sugary pulp forms a slimy discoloured mass unevenly distributed over the surface of the seed integument. In some countries the fermented seeds are cured in the sun or in drying houses without any treatment whatever, but in others the slimy residue is removed by washing them in cold water before subjecting them to the curing or drying process. The washing usually consists of placing the fermented seeds in baskets or receptacles which are kept in violent motion while subjected to a stream of flowing water, for a few minutes only; the receptacles are kept in motion either by the use of machinery or by hand, the former being advantageous on estates with large acreages of cacao in bearing.

The Washing Process in Tropical America and the West Indies

Preuss states that the cacao in Surinam is dried without washing, as the American market, which is a big buyer of unwashed cacao, does not attach as much importance to the external appearance of the cacao as the Hamburg market, and the planters obtain an increased yield by not removing the surrounding pulp.

In Nicaragua, washing the fermented cacao is not customary, the drying facilities being obviously advantageous in some districts; in Salvador and Guatemala the cacao is usually washed before being cured. In a general way it may be said that the cacao is not usually washed in South America and the Antilles, though washing appears to be adopted in parts of Central America.

In the two principal cacao-growing West Indian islands—Trinidad and Grenada—washing of cacao is not usually adopted, the increase in weight being considered of importance.

The difference in the methods adopted in various parts of the tropics in respect to this process are remarkable, but it is generally conceded that washing is not necessary where perfect drying apparatus is provided, but may be advisable and even necessary in countries where no such apparatus is employed, or where a period of dry weather during crop time cannot be relied upon.

Advantages and Disadvantages of Washing Cacao.

The advantages and disadvantages of washing cacao are only too well-known; they are mainly determined by the requirements of the particular markets, some objecting to and others favouring washed cacao. Whatever may be said, it is certain

that unwashed cacao is less clean and heavier than washed, and weight for weight contains a lower proportion of essential substances; a reduction in its value, when sold by weight, is therefore to be expected.

The unwashed seeds, owing to the residual dried pulp, may show distinctive differences in taste and colour; they may become more pliable, and their adaptability to polishing may be improved. Preuss is of the opinion that the comparatively weak but fine aroma of some washed cacao of Central America, such as the Guatemala, Salvador and Tobasco, is attributable partly to the washing, and points out that the unwashed cacao of Venezuela, Guayaquil, and Trinidad has a much stronger taste. He also mentions that the cacao of Cameroon, though it is washed, has a very strong taste, proving that other factors need to be considered.

In most parts of Ceylon and in parts of West Africa, Samoa, and other countries the washing process is usually carried out, but in other equally important cacao countries this process does not find favour among the planters, the belief being that the lower price of the unwashed cacao is more than counterbalanced by the increase in weight. It should be clearly understood that the differences in value of the ordinary washed cacao from Ceylon and the unwashed cacao from other countries are not wholly attributable to the washing process but more to the variety of cacao cultivated in the various places; the point at issue can only be tested by making experiments with seeds from the same variety in the same country. Johnson*, from the results of his experiments on the Gold Coast and valuations received on the Hamburg market, concluded that it would be more profitable for the grower to send his cacao to the market unwashed, as its weight is decreased by the washing operation, and a certain amount of extra labour is entailed. But in his experiments it was obvious that the valuations of the different samples were contradictory, and the washed and unwashed samples do not appear to have been of the same variety judging from the reports of Rachwitz, Bluhm, and others.

As a typical example of a report in favour of abolishing the washing process, the following by S. H. Davies† is of interest:—"My reply to your questions concerning the advantages of washing cacao would be:—(1) The loss of weight is appreciable and might amount to 2 or 3 per cent., a serious item when dealing with large quantities of cacao; (2) Washing renders the cacao more friable; (3) If the brokers are accustomed to Jamaica Cacao with a certain appearance, they will resent any change; they are conservative and have many strange conventions about the appearance of cacao; (4) Removal of the pulp by washing will not greatly reduce the time of drying. On the whole I should advise against

* Annual Report. Botanic Gardens. Gold Coast, 1904; W. H. Johnson.

† Bulletin, Vol. VII., Part VIII., Botanical Department, Jamaica. August, 1900.

washing cacao. All this applies to a properly fermented cacao, not to the native dried stuff."

The above conclusions, though correct in the main, require slight modification. In Ceylon it is very difficult to effect a good cure of unwashed cacao if the sun is not strong or if the atmosphere is very moist, and on estates which do not possess artificial drying houses, the curing of unwashed cacao is often disastrous in the wet season. The residual pulp has strong hygroscopic properties, and mould readily appears on the covering during the damp weather and the cacao becomes very dark on the surface. The removal of the pulp by washing, under such conditions, allows one to more rapidly and effectively dry the fermented seeds. The outstanding advantage of unwashed cacao is the increase in weight obtained thereby, and it remains to be proved whether this will compensate for the reduction in price in material from the same variety prepared by both processes.

Washing Cacao and Loss in Weight: Experiments in Ceylon

Several experiments have been carried out, in connection with this subject, at the Experimont Station, Peradeniya. In one experiment the fermented seeds were cured in the sun without washing—a practice said to be adopted with favourable results in parts of the West and East Indies. The cured seeds differ from those which have been washed before curing, in that the testa is much darker and that there is a decided increase in weight. The seeds which were cured without washing had finally to be placed with the "black" cacao; the finished article had a dirty appearance, and was very hygroscopic in consequence of the soft pulp around the seeds not being removed, and this subsequently led to the appearance of mould over the seeds. On the other hand, the unwashed seeds had a sweet taste and showed an increase in weight. The following figures show the increase in weight when the seeds were cured without washing:—

		Average Weight of each Seed in Grams.
I.	Caracas, not washed, 45 seeds = 57·7 grs. ...	1·28
	Caracas, washed, 388 seeds = 460·5 ,, ...	1·19
	Control, 1,795 washed beans = 2250 ,, ...	1·25
	The increase in weight of un-washed beans varied from 0·03 to 0·09 grs. per seed; equivalent in the above case to an increase of from 2 to 7 cwt. per 100 cwt.	
II.	Forastero, not washed, 470 seeds = 591·1 grs. ...	1·26
	Forastero, washed, 433 seeds = 519·5 ,, ...	1·20
	Control 1,200 washed seeds = 1550·6 ,, ...	1·25
	The increase due to not washing the seeds was 0·01 to 0·05 grs. per seed or equivalent to an increase of ¾ to 5 per cwt. per 100 cwt.	
III.	Seeds washed before being cured in sun. 490 seeds = 656·60 grs.	1·29
	Seeds not washed, exposed direct from fermented heap, 362 seeds = 464·40 grs.	1·31

The increase of 0·95 per seed in this batch was equivalent to an increase of nearly 4 cwt. per 100 cwt.

The increase in weight noticeable in all these cases was due (*a*) to the presence of the pulp surrounding the seeds; (*b*) to the water absorbed by this shrunken pulpy layer and the moulds which establish themselves thereon.

From the results of these experiments one might be inclined to think that it is very doubtful whether the increased weight of unwashed cured beans will compensate for the loss in quality.

Loss on Washing Cacao in Africa.

The loss in weight, incurred by washing cacao, varies according to the varieties; those cultivated in Surinam, Ecuador, and Trinidad have often a much more bulky pulp than those of Central America and the Venezuela-Criollo. If it is correct that the loss on washing may sometimes equal 15 per cent. one can easily understand why the washing operation is omitted, but such a high percentage of loss does not occur with the cacao in Ceylon.

Preuss has recorded his observations on this subject, and the following results were obtained by him with cacao in Cameroon:—

A. 100 washed beans weighed	= 113 grams.
1. Weight of nibs or kernels	= 91·33 per cent.
2. Weight of shells or integuments	= 8.66 ,, ,,
B. 100 unwashed beans weighed	= 121·25 grams.
1. Weight of nibs or kernels	= 87·5 per cent.
2. Weight of shells or integuments	= 12·5 ,, ,,

These results showed that by washing Cameroon cacao the loss was about 3.83 per cent., an amount which is much nearer that recorded elsewhere for Ceylon than the 15 per cent. quoted above.

In many countries it has been recorded that the unwashed cacao dries less rapidly and is more liable to mould; this is a disadvantage in many countries, but it is obviously one which can be neglected on estates where the cacao drying apparatus is in perfect condition. Unwashed cacao can, according to Preuss, stand higher temperatures than the washed beans, and these are consequently better able to pass through the roasting process with the minimum damage.

Other experiments have been made by Eigen* in Cameroon which prove that an appreciable loss in weight occurs on washing. In his experiments different samples of equal weight were taken from the same fermenting heap, some washed and others unwashed. They were then dried separately in the sun; a period of five days being allowed to dry the washed cacao and seven days for the unwashed. The 5 kilograms of washed and cured cacao weighed after complete drying 2.20 kilograms and the unwashed 2.340 kilograms. The loss due to washing was there-

* Der Tropenpflanzer, February, 1903, p. 60.

fore calculated to be about 6 per cent., and as washed cacao from Cameroon seemed to obtain the same price as the unwashed, on the Hamburg market, Eigen considered it would be better to cure the seeds without washing.

Curing or Drying Cacao.

The fermented seeds, sometimes washed and at other times unwashed, are either dried by exposure to the sun or in hot air or vacuum chambers, the process having for its object the removal of water, production of a friable product of suitable colour, and destruction of the embryo. The colour of the exterior and of the kernel is changed during the curing process to a brown or chocolate tint, and the extraction of moisture and high temperature during the exposure are responsible for the death of the embryo.

In Ceylon, and in most tropical countries, curing by exposure to the sun and wind is adopted whenever possible, as by this means a final product of high quality is produced with the minimum cost of labour, etc. When climatic conditions are unfavourable for short intervals only, the cacao is alternately dried in the sun during fine weather, and in covered sheds at ordinary temperatures while the rain is on ; but when wet weather prevails for the greater part of the day curing houses supplied with hot air are resorted to.

It is asserted by many that drying in the sun gives a more uniform product than that obtained when artificial drying is resorted to, and that on account of its cheapness it is to be strongly recommended. It is also maintained that drying in the sun gives a brighter and redder cacao, especially when it has been washed after fermentation. It is obvious, however, that where the climatic conditions are such as to prevent drying in the sun, some form of drying apparatus must be available.

Characters of Cured Cacao.

The curing is considered to be complete when the surface of the bean has a bright reddish-brown appearance, the kernel a brown or chocolate colour internally, and when the parts are friable and show no signs of moisture or uneven colour on breaking. In Ceylon the seeds are not usually protected from exposure to the sun during the hottest part of the day, as appears to be the case in some parts of the West Indies, though such protection would appear to be advantageous on certain days in the hot season in order to prevent the kernel from drying too rapidly, A slow curing with a relatively low temperature often produces better cacao, and it is generally agreed that curing should not be completed in less than three days. When the cacao is cured too quickly the testa or integument often leaves the substance of the kernel, and is subsequently very friable and easily broken; this is especially the case with cacao which has been washed, but it also occurs in rapidly cured unwashed samples. The same phenomenon takes place when the drying chambers are maintained at excessively high

temperatures, and on account of this liability most cacao planters prefer to cure the seeds as slowly as possible after the first day, providing moulds do not appear on the surface. In some parts of Trinidad, Venezuela, and other places the drying of the slimy residue is difficult, and in order to hasten this the surfaces of the fermented and unwashed seeds are, after their first day's exposure to the sun, sprinkled with finely divided red earth, brick dust or red ochre, the object being to absorb the moisture from the superficial slimy residue and to give the final product a better colour.

Curing in the Sun.

When cacao is dried in the sun, it is usually spread out on floors of cement, brick earth covered with coir matting, glazed earthenware or slabs of slate, or on other material which can be easily and effectively cleaned; the floor is generally constructed with a slope so that water may easily escape. Sometimes drying wagons are constructed on wheels so as to be easily run out for exposure during fine weather or under shelter when rain begins to fall; in other cases the wagons are fixtures, but are covered with movable roofs which can be adjusted rapidly according to requirements.

The most usual method in Ceylon is to spread the wet seeds over large floors covered with coir matting; or on floors specially constructed so as to be easily cleaned and to allow the moisture to run off in a definite direction. The fermented and washed cacao is usually arranged one or two seeds deep, and repeatedly turned over every few hours by means of a rake; during each day the seeds are exposed for six to eight hours and after three or four days of good weather are completely cured. Wooden floors or trays, which can be readily covered during wet weather or when the temperature is too high in the middle of hot sunny days, are sometimes used.

In Surinam where the rainfall is about 2500 mm. per year, many opportunities occur for drying the cacao by exposure to the sun, as this method is not only the cheapest but often gives very good results. In some cases the cacao is simply dried on cement or dry floors, which have their highest point in the middle and gradually slope in all directions so as to allow the liquid materials to run off quickly; often, however, the cacao is cured in flat wooden structures which are placed on wheels in order to allow them to be run under cover quickly in rainy weather; in some cases the drying places are permanent and covered with a movable roof which can be used according to requirements in wet and dry weather.

The length of time required for effectively curing the cacao by exposure to the sun and wind varies according to the prevailing weather, depth of the seeds, and the amount of fermenting and washing which has been allowed. Washed and lightly fermented

Photo by H. F. Macmillan.

CURING CACAO IN THE SUN.

cacao can, in Ceylon, be cured in three or four days during fine weather and in about one week under less favourable climatic conditions.

Drying Apparatus.

When weather is uncertain or where there is a long rainy season during crop time, artificial drying apparatus must be provided. Small drying apparatus is sometimes made in the form of an oven, fitted up with strong moveable wire shelves for drying the cacao and turning it over, the heating apparatus being inside or outside the oven and the hot air conducted through all parts by means of pipes, and the saturated air allowed to escape through a valve. The Blackman Air Warmer is said to be constructed to effectively dry 60 cwt. of cacao in 36 hours, and other apparatus is designed to dry 32 cwt. of cacao in two days.

In Surinam artificial drying apparatus is often used, and according to Preuss the forms met with are (1) Ryder's Patent, an apparatus for drying cacao which has been frequently used in Cameroon, (2) the apparatus by Henry Hemans and Company, London, (3) Huizer's Droog-Vorrichtung, and (4) Jose Guardiola's patent. The two latter drying contrivances were originally constructed for coffee, but have since been modified to suit the purpose of cacao curing. In Huizer's apparatus the cacao is dried on a circular perforated metal plate about ten metres in diameter; heat is supplied by means of a system of pipes filled with steam, and a contrivance exists for preventing the escape of hot air. The plate revolves at intervals, and it is stated by Preuss that in fifty hours, 3600 kilograms of cacao can be effectively dried. The cacao beans are arranged to a depth of 10 cm. and must be frequently turned over. In Guardiola's apparatus the cacao is dried on a different principle; the cacao is placed in large horizontal cylinders, well supplied with perforations and heated by hot air pipes. When the cylinder is set in motion the cacao is thoroughly mixed and the moist air escapes through the numerous perforations; it is usual to first dry the unwashed cacao in the sun before putting it in the cylinder, as otherwise pulpy substances are apt to clog the perforations. It is claimed that this apparatus is capable of curing 2000 kilograms of cacao in 36 hours, and that it produces a cacao bean with a highly polished surface on account of the rubbing which takes place when the cylinder is in motion.

Drying Houses.

A moderate spacious drying or curing house, well supplied with heating and ventilating apparatus, is perhaps the most economical for the average estate, as when crop time is not on, it can to some extent be used for many other purposes, such as storing, packing, etc. The roof of the lower chamber may constitute the drying space, or special shelves may be erected for this purpose. Where either method is adopted, the hot air can be allowed to enter at one end and the saturated air be drawn out at the opposite end by means of a fan; hot air or steam pipes may be arranged

to run through the room to raise the temperature according to requirements. Where series of trays are used, the pipes can be arranged under the bottom series so as to avoid obstruction along the pathways, though this is open to the objection that the cacao on the lower trays may be dried much more rapidly than the rest.

Single Chambers.

Preuss has described one in use in the West Indies which consists of a single chamber, 10 metres long, 6 metres broad and 3 metres high, closed on all sides. Running lengthways and in the middle of the room are rows of perforated trays, arranged in tiers one above the other. In each of two corners is an oven from which a pipe 30 cm. in diameter (nearly 12 inches) issues; the pipes run under the rows of the trays in the middle of the room, then bend round to the right and left respectively, and continue under the trays on each side and back to the oven. In this way the air may be heated, and when charged with moisture drawn off by means of a fan. A room constructed in this way would allow two pathways between the middle row of the trays and those on the sides, each to be entered by means of a door placed at the end of the building opposite the heating apparatus.

Curing Houses in Ceylon.

In Ceylon, there are numerous types of cacao curing houses and perhaps one of the first to receive conspicuous public attention was that adopted by the late Mr. Jeffries at the Experiment Station, Peradeniya, prior to the Ceylon Government taking over the cacao estate for economic experimental purposes. Trimen* in his account of the apparatus wrote as follows:—"The house is about twice as long as broad, built of brick and is provided with double doors, but with the exception of the opening for the ingress and egress of the hot air is hermetically sealed. The interior is fitted with a number of upright frames into which slide, one above the other, the trays upon which the beans are spread; these should be made of narrow pieces of split bamboo, not of wire or coir matting. The heating apparatus is outside in contact with one end of the building, and consists of a large stove standing in a short tunnel which opens into the house. At the other end of the building, also outside, is a powerful fan fitted in another tunnel; this is worked by hand (three or four coolies needed) and by its rapid revolution draws the air through the house. By passing over and round the stove the air is dried and heated; that which passes out is hot and damp. The flue of the stove passes under the floor of the house and contributes to warm it. A drying house of this sort is very simple, and it costs only about £100; it does its work perfectly, and nothing more elaborate or costly is required." This apparatus was, however, subsequently discarded and a curing house built on principles more in accord with those successfully used in various parts of Ceylon.

* Trimen, Annual Report, R.B.G., Peradeniya.

Most of the curing houses in use in Ceylon consist essentially of two chambers, the lower one being spacious and specially adapted for receiving the hot air, and the upper one the fermented seeds. The coir matting on the floor of the upper chamber is covered with the freshly-fermented seeds; the hot air passed through this mass from below upwards, and the moist air is drawn off by means of a fan. In most cases the hot air is drawn through the chamber by means of a fan driven by hand or power and positioned at the opposite end of the chamber away from the heating apparatus; in some cases, however, the hot air is driven through the lower chamber and allowed to escape at the end of the building opposite to the fan. The air space beneath is usually very spacious, and by means of a series of brick baffle plates the air may be made to travel throughout its length before commencing to ascend.

Many planters in the West Indies seem to think that a cacao drier constructed on the principle of that described by Trimen as in use in Ceylon, is the one most likely to give satisfactory results. But it should be clearly understood that the drying apparatus adopted by Jeffries in Ceylon is not considered to be the best, and it is very doubtful whether one of the old type exists here at the present time, most planters preferring the two-storeyed rooms, with the lower one very spacious.

Cacao Drying in the West Indies.

Mr. G. Whitfield Smith, travelling Superintendent of the Imperial Department of Agriculture, West Indies, has given, in the West Indian Bulletin (Vol. 11., pp. 171-4), an account of a cacao drier made in Grenada and since erected by the Department at the Botanic Station, Dominica. In the Agricultural News, Barbadoes, (Vol. 1., p. 19) it is stated that:—"The essential feature of this drier is the arrangement by which the hot air, on entering the drying box, is conducted along an air-tight flue or channel, and is compelled to pass over and around series of trays in succession, beginning with the lowest. In this respect it is a great improvement on driers of a similar pattern used in Grenada and elsewhere, which have no interior divisions. In such driers it is found that the hot air on entering the single drying chamber naturally rises to the top, with the result that the beans on the upper tray were too quickly dried, while those on the lower tiers were only partially dried or, in some cases, remained moist. The drier is capable of dealing with five bags of cacao at a time, and its original cost including shed, stove, and fan, was £127. Where, however, the planter is able to utilise a spare building in which to place the drying box and stove, the cost might be reduced by about one half." It is further stated that the best results were obtained by maintaining a temperature of 110° to 112° F., with a good draught passing over the beans. Similar driers have been erected on private estates, and are reported to have proved thoroughly successful.

In the Jamaica Bulletin for September, 1905, an account of one form of a cacao-drying apparatus, erected by Hoadley at Chaguanas, Trinidad, is given. The apparatus consists of a room 34 feet square, with a perforated circular drying floor, upon which the wet fermented cacao is placed. In the centre of the drying tray is an arrangement by means of which the cacao is kept in motion. Air is drawn over pipes charged with exhaust steam by a powerful fan which makes from 600 to 700 revolutions per minute, and is thereby heated to any desired temperature up to 150° F. and is forced up through the drying floor. It is stated that by means of this arrangement from 12 to 15 bags of cacao can be dried in thirty to thirty-six hours. According to the Agricultural News, Barbadoes a "drier" at L' Esterre estate has been made from designs furnished by the Blackman Ventilating Co. of London. In this drier the hot air is forced through the drying box by reversing the action of the fan and placing it immediately over the furnace: great difficulty was at first experienced in forcing the hot air through the entire length of the drying chamber. This difficulty has now been met by placing an exhaust fan at the end of the drying box farthest from the furnace.

Preuss has given some interesting accounts and detailed sketches of various types of curing houses in use in different parts of the West Indies and Tropical America, and reference should be made to his work on this part of the subject.

Loss During Curing.

The loss in weight which occurs during the fermenting process has already been touched upon, and though of some importance it is outweighed by that which occurs during the curing process. The loss in weight during curing is one which is accompanied by the minimum chemical changes, the chief factor being the loss of water during drying, by simple evaporation. In order to give some idea of the proportionate loss during the processes of curing and fermenting, and the total quantity of dry cacao obtainable from a known weight of wet cacao fresh from the fruits, the following details of the results of experiments at Peradeniya are given:—

Kind.	Before Fermenting.	After Fermenting.	After Washing.	After Curing.	Total loss.
	lb. oz.	lb. oz.	lb. oz.	lb. oz.	Per cent.
Caracas ...	19·0	16·12	15·2	7·10	59
Caracas ...	321·0	294·0	280·0	117·0	63
Forastero ...	307·0	258·6	247·0	118·0	61
Forastero ...	313·0	273·0	255·0	110·0	64
Amelonado ...	101·0	84·8	77·14	39·2	61
Amelonado ...	95·0	81·0	77·0	32·0	66
Mixed ...	439·0	392·0	—	163·0	62
Mixed ...	250·0	210·0	200·8	97·0	61
Mixed ...	250·0	205·6	193·8	95·0	62
Mixed ...	250·0	197·10	186·12	94·0	62

Hart* has also published the results obtained at River estate, and the following are the available details:—

	lb.
A picking of 11 barrels of wet cacao weighed when brought in ...	2,600
(*a*) The loss during fermentation was 15·5 per cent. or.. ...	403
(*b*) The loss of weight in drying after fermentation, was 54·44 per cent. or	1,195
(*c*) The total loss during drying and fermentation 61·46 per cent. or 1,598	1,598
Marketable cacao produced ...	1,002

These results agree in general with those obtained at Peradeniya, but it is unfortunately not stated what varieties were experimented with at Trinidad.

Colourig and Polishing Cacao.

The majority of the cacao in Ceylon does not usually receive further attention after curing and sorting operations are complete, the cacao being shipped as soon as possible. In the West Indies, however, the cured seeds are frequently coloured by the use of brick dust, red earth or red ochre, to improve the appearance of the integument; this treatment is obviously accompanied by a variable increase in weight, dependent on the details of the operation. Finely-divided red earth is said to give the best colour and to be least objected to by the buyers.

The substances thus applied, being in a fine state of division and perfectly dry, serve to absorb a certain amount of moisture, and in addition to giving a definite colour provide a superficial coating of foreign material which assists in the polishing process.

The polishing process is done either by rubbing the seeds by hand, by the feet of the coolies in the dancing operation, or by means of brushes; the use of brushes is relatively recent. The polishing of cacao is a harmless operation, but it is difficult to see the real necessity and in many instances the wisdom of adding foreign material to, or polishing the surface of, the seeds; in Ceylon these processes are not known on well-managed properties, though one cannot say what happens among native merchants. In order to avoid any misunderstanding the following passage is quoted from Hart's book, regarding these processes in the West Indies:—"In Trinidad various mixtures are used for colouring purposes and for bringing out the polished appearance of the cacao; among them may be mentioned starch, red ochre, roucou or annatto, and red earth or clay. The red clay of San Antonio Estate, Trinidad, is described by the late J. J. Bowrey, Government Analyst, Jamaica, as a very fine ferruginous clay free from organic matter, and is said to answer the purpose

* Bulletin of Misc. Inf., October, 1905, Trinidad.

admirably. Dressing or colouring of cacao is however more practised by merchants who purchase from the small growers than by the well-to-do planter, as by this means they are able to put an even appearance on samples of different qualities; but cacao of finest quality and appearance can be made without the addition of any single particle of extraneous matter, if the methods of the best estates are adopted." The unwashed cacao is said to lend itself to these processes of colouring and polishing better than the washed material. The colouring and polishing materials, if applied, should be well dried and mixed with the cacao seeds the second day after drying; the unwashed cacao is said to keep better after being subjected to this treatment.

CHAPTER XI.

PHYSICAL AND CHEMICAL CHARACTERS OF CACAO SOILS.

THOUGH it is commonly understood that cacao is not a very exhausting crop, there are few men of experience who will deny that it thrives best in soils possessing good physical and chemical properties. Jumelle points out that the best cacao soils are those which have been uncultivated for many years, or not at all, and that abundance of humus, 1 to 2 per cent. of lime, and 0·25 per cent. of phosphoric acid as well as abundant supplies of other ingredients are necessary, before one can hope to obtain the best results.

Alluvial soils or rich marls are suitable for cacao, but hard clayey soils or briny ones directly exposed to sea water are inferior. in America the best cacao is said to be cultivated along the coast, provided it is beyond the reach of sea water or strong sea breezes; in the interior cacao is grown mostly in the valleys protected from strong winds and supplied with abundant moisture.

In order to give the reader an idea of the cacao soils in various parts of Ceylon, West Indies, tropical America and Samoa, somewhat detailed references have been made from the published accounts of Cockran, Couturier, Bamber, Bruce, Hart, Harrison, Wohltmann, and others. In these analyses a considerable variation is shown to exist and certain characteristic percentages of several constituents are shown to be associated with the cacao-producing capacity of the soil; differences in chemical composition, though often very important, are nevertheless of but little comparative value except they are associated with the physical properties of the soil and the local climatic forces. Soils at Peradeniya have often been pronounced to be inferior from a chemical standpoint, but, owing to their mechanical composition and general physical properties have produced better cacao crops than many of the rich and specially manured plots.

Nitrogen and Mineral Constituents.

Soils richly supplied with potash are said to give the best yields of cacao, and the following figures, drawn up by Couturier,*

* La Fumure du Cacao, by M. A. Couturier, Journal D' Agriculture Tropicale, No. 27, Sept. 30, 1903.

from the analyses published by Lecomte* and Chalot, are quoted to show the relative proportion of essential ingredients in soils from different countries :—

	Potash.	Phosphoric acid.	Nitrogen.	Lime. (Chaux)
Grenada (Hart) ...	0·041	0·024	0·137	0·534
Saint-Vincent (Hart)	0·083	0·042	0·075	4·800
,, ,, ,,	0·178	0·114	0·205	5·000
Guadeloupe (Boname)	0·111	0·124	0·205	0·173
Martinique (Rouf) ...	0·111	0·243	0·211	1·300
Trinidad (Hart) ...	0·183	0·133	0·131	0·128
,, ,, ...	0·267	0·117	0·140	0·124
Grenada (Hart) ...	0·343	0·184	0·271	2·379
Venezuela (Hart) ...	0·392	0·147	0·071	0·594
Reunion ...	0·580	0·400	0·300	0·350
Nicaragua (Hart) ...	0·619	0·293	0·228	2·250
Surinam (Hart) ...	1·040	0·110	0·270	0·400
,, ,, ...	1·070	0·140	0·300	0·500

Only the two first soils yield poor cacao crops. The last four are exceptionally rich from a chemical standpoint, but it is admitted that the physical properties are probably of more importance. Harrison, Cockran, and others have frequently pointed out that the potassic constituents appear to exert a greater influence on the productiveness of the cacao trees than the phosphoric acid and nitrogen.

Cacao Soils in the West Indies, America, and Ceylon.

The many analyses of cacao soils which have been published allow one to draw up a good table of comparison between those of Samoa, the West Indies and tropical America—including Demerara, Grenada, St. Vincent, Trinidad, Nicaragua, Surinam, and Venezuela, and those of Ceylon. In the following table the range in composition of the various cacao soils, with reference to the more important ingredients, is given :—

	West Indies.	Ceylon.
	Per cent.	Per cent.
* Organic matter and combined water.	2·786 to 18·701	2 to 15
Lime	Traces to 4·787	0·02 to 0·35
Magnesia	0·041 to 3·367	0·05 to 0·3
Potash	0·041 to 1·172	0·03 to 0·4
Phosphoric acid	0·002 to 0·293	Traces to 0·1
* Containing nitrogen	0·057 to 0·309	0·1 to 0·5

* Le Cacaoyer et sa Culture, Paris, 1 97.

The table given elsewhere showing the proportion of lime, nitrogen, phosphoric acid, and potash in soils from other parts of the West Indies, based by Couturier* upon the analyses of Harrison, Boname, and Rouf agree approximately with those given above if allowance is made for the different method of expressing percentages. The soils of Surinam appear to be often very rich in potash, organic matter, and nitrogen, those of some parts of Grenada rich in magnesia, and those of parts of Nicaragua and Martinique, in phosphoric acid. Lime is recorded in very large proportions from many of the soils of St. Vincent, Grenada, and Nicaragua.

In each country, however, a wide range in composition is usually to be found. And even soils from the same district may present differences in mechanical and chemical characters which render a comparison of different countries misleading or useless.

The cacao soils of Ceylon when compared with those in many parts of the West Indies are usually found to be inferior as regards the percentage of lime, magnesia, and potash, though the organic matter, nitrogen, and phosphoric acid in Ceylon samples of soils appear to be often more abundant than in the average cacao soils of the West Indies.

Constituents in Good and Inferior Cacao Soils.

The proportion of essential constituents in soils which are known to give good and inferior crops has been given by Hart and from the numerous West Indian analyses the following table has been drawn up to show the range of these ingredients :—

	Good cacao soils.	Inferior cacao soils.
	Per cent.	Per cent.
* Organic matter & combined water ...	3·76 to 15·45	1.92 to 18.70
Calcium oxide ...	0·35 to 4·98	Traces to 4.78
Magnesium oxide ...	0·21 to 3·36	0.04 to 1.89
Potassium oxide ...	0·16 to 1·07	0.02 to 0.10
Phosphoric anhydride ...	0·04 to 0·29	0·002 to 0.15
* Containing nitrogen ...	0·10 to 0·30	0.05 to 0.26

These tables indicate a relatively lower percentage of the essential ingredients in the soils giving unsatisfactory yields, especially in the potash and lime. It would, however, be unwise to base

* M. A. Couturier, l. c.

deductions on these differences alone; they can be better considered in association with other factors.

Ceylon Cacao Soils.

Cockran * publishes the following analyses of soils in Ceylon, on which the Forastero and Caracas varieties were successfully grown:—

Cacao Soils in the Air-dried State; Mechanical Analyses.

	No. 1. Forastero Field. Per cent.	No. 2. Caracas Field. Per cent.
Coarse earth	60·75	39·25
Fine Earth	39·25	60·75
	100·00	100·00

Chemical Analysis of the Fine Earth.

Moisture	2·950	3·200
(a) Organic matter and matter lost by ignition	7·994	5·150
Oxide of iron	6·793	5·855
Alumina and oxide of Manganese ...	8·021	8·253
Lime...	0·793	0·700
Magnesia	1·130	0·632
Potash	0·884	0·274
Phosphoric acid..	0·062	0·192
Silica, insoluble silicates, and matters not determined	71·373	75·744
	100·00	100·00
(a) Containing Nitrogen	0·193	0·070

The above analyses show the composition of cacao soils in the Central Province, Ceylon, but numerous others have been made and published by Bamber and Bruce of the cacao soils in the Peradeniya districts, from which the yearly yields of cacao have been determined.

* Annual Report, Planters' Association of Ceylon, 1899.

Ceylon Cacao Soils: Peradeniya District.

The following* are the analyses of several soils from cacao plots at the Experiment Station, Peradeniya :—

Mechanical Composition.

	Plot No. 1.	Plot No. 2.	Plot No. 3.	Plot No. 4.
	Per cent.	Per cent.	Per cent.	Per cent.
Fine soil passing 90 mesh ...	48·00	42·00	40·00	42·00
Fine soil passing 60 mesh ...	42·00	40·00	38.00	38·00
Medium soil passing 30 mesh ...	8·00	14·00	16·00	14·00
Coarse sand and small stones ...	2·00	4·00	6·00	6·00
	100·00	100·00	100·00	100·00

Chemical Composition.

	Plot No. 1.	Plot No. 2.	Plot No. 3.	Plot No. 4.
Moisture	3·600	2·600	3·000	3·000
* Organic matter and combined water ...	4·600	4·600	4·000	4·000
Oxide of iron and manganese	7·200	4·400	4·400	5·600
Oxide of alumina ...	6·786	4·818	8·147	7·547
Lime	0·160	0·140	0·140	0·140
Magnesia	0·216	0·202	0·202	0·144
† Potash	0·077	0·092	0·077	0·170
‡ Phosphoric acid ...	0·064	0·089	0·076	0·064
Soda	0·233	0·199	0·296	0·284
Sulphuric acid	0·048	0·048	0·048	0·041
Chlorine	0·016	0·012	0·014	0·010
Sand and silicates ...	77.000	82·800	79·600	79·000
	100·000	100·000	100·000	100·000
* Containing nitrogen ...	0·100	0·112	0·112	0·106
Equal to ammonia ...	0·122	0·136	0·136	0·129
Lower oxide of iron ...	Trace	Trace	Nil	Nil
Acidity ...	Fair	Faint	Fair	Fair
† Citric soluble potash ...	0·008	0·008	0·008	0·013
‡ Citric soluble phosphoric acid	Trace	Trace	Trace	Trace

Mechanical Composition.

	Plot No. 96.	Plot No. 98.	Plot No. 99.	Plot No. 100.
	Per cent.	Per cent.	Per cent.	Per cent.
Fine soil passing 90 mesh ...	60·00	28·00	28·00	30·00
Fine soil passing 60 mesh ...	28·00	18·00	20·00	22·00
Medium soil passing 30 mesh ...	5·00	14·00	12·00	10·00
Coarse sand and small stones ...	7·00	40·00	40·00	38·00
	100·00	100·00	100·00	100·00

* Circular, R. B. G., Peradeniya, 1905, A. Bruce, Assistant Chemist.

Chemical Composition.

	Plot No. 96.	Plot No. 98.	Plot No. 99.	Plot No. 100.
Moisture	3·200	1·600	3·000	3·200
* Organic matter and combined water ...	9·200	7·200	9·000	9·400
Oxide of iron and manganese	7·200	4·800	8·000	8·000
Oxide of alumina ...	10·370	7·258	6·469	7·184
Lime	0·080	0·080	0·100	0·100
Magnesia	0·072	0·144	0·130	0·100
† Potash	0·100	0·208	0·170	0·100
‡ Phosphoric acid ...	0·076	0·102	0.089	0·102
Soda	0·192	0·146	0·178	0·129
Sulphuric acid ...	0·068	0·048	0·048	0·055
Chlorine	0·042	0·014	0·016	0·030
Sand and silicates ...	69·400	78·400	72·800	71·600
	100·000	100·000	100·000	100·000
* Containing nitrogen ...	0·123	0·095	0·123	0·123
Equal to ammonia ...	0·119	0·115	0·149	0·149
Lower Oxide of Iron ...	Nil	Much	Trace	Trace
Acidity	Fair	Fair	Fair	Fair
† Citric soluble potash ...	0·008	0·015	0·013	0·008
‡ Citric soluble phosphoric acid	Trace	Trace	Trace	Trace

In the description of these soils, it states that they "are brown quartzy loams in a fine state of division. The organic matter is very poor, but carries with it a fair supply of nitrogen. In mineral plant food there is a fair proportion of lime, and the magnesia is present in good quantity; the potash is sometimes present in comparatively large quantity, as in plot No. 98 while the others have a fair supply, but plots 1-3 are rather deficient. The citric soluble potash is generally low and the phosphoric acid is poor, although in numbers 98 and 100 there is a fair supply; only traces are citric soluble. Acidity is present in all cases, and in many it is marked. Comparing the analyses of the soils which have been growing cacao with the analyses of other plots which have been under jungle for some time, it will be seen that the cacao soils are much impoverished". It should be mentioned that the soils numbered 1, 2, 3, and 4 gave during 1905 respectively 18,546, 14,376, 12,826, and 11,627 mature cacao fruits, per acre, and those numbered 96, 98, 99, and 100 from 8,000 to 13,000 fruits per acre, per year, under proper cultivation.

Soils in the Matale District.

The soils characterising the Matale District are frequently similar to those near Peradeniya, and the following notes* from a previous publication are now quoted:—

Mechanical Composition.—"The soils from the Matale District are on an average in a better state of division than those in the

* Circular, R. B. G., Peradeniya, Para Rubber, by Herbert Wright and A. Bruce.

districts previously dealt with, usually from 15 to 30 per cent. passing through a 90 mesh, 14 to 25 per cent. through a 60 mesh, and 3 to 7 through a 30 mesh. Sand and small stones may form from 40 to 60 per cent. of the soil. The retentive power for moisture of air-dried soil does not show a very great variation, and is from 3 to 6 per cent.

Chemical Composition.—The organic matter usually varies from 8 to 14 per cent., and the nitrogen from 0·1 to 0·2 per cent.; the lime from 0·08 to 0·2 per cent.; the magnesia from 0·05 to 0·25 per per cent.; the potash from 0·03 to 0·25 per cent., and the phosphoric acid from 0·01 to 0·1 per cent."

Kurunegala District.

The rainfall of 75 to 100 inches is evidently suitable for cacao, and a glance at the average composition of the soil would not be out of place here. The soils vary greatly, as can be seen from the following figures :—

Mechanical Composition.

	Per cent.
Fine soil passing 90 mesh	17 to 35
Fine soil passing 60 mesh	20 to 35
Medium soil passing 30 mesh	5 to 9

Chemical Composition.

	Per cent.
Coarse sand and small stones	20 to 60
Moisture	3 to 7
Organic matter and combined water ...	4 to 8
Lime	0.1 to 0.35
Magnesia	0.1 to 0.45
Potash	0.08 to 0.18
Phosphoric acid	0.02 to 0.04
Nitrogen	0.08 to 0.11

During 1905 and 1906 cacao as a single product and in association with Para rubber has been largely planted.

Passara and Moneragala Districts.

According to the District Association's reports large areas in Moneragala and the lower elevations of the Uva Province have been planted in cacao. In the Uva Province the climatic conditions are said to be such as to allow the cultivation of cacao and Para rubber up to an elevation of nearly 3000 feet. "Very few soils have been analysed from the Province of Uva, but from those obtained from Passara

the following information has been compiled. Usually from 17 to 30 per cent. passes the 90 mesh, 20 to 30 per cent. the 60 mesh, 7 to 8 per cent. the 30 mesh, and sand and small stones form 40 to 43 per cent. The retentive power of moisture is about 25. The chemical analyses show the presence of from 7 to 11 per cent. of organic matter, 0.1 to 0.15 per cent. of nitrogen, 0.06 to 0.1 per cent. of lime, 0.07 to 0.13 per cent. of magnesia, 0.05 to 0.08 per cent. of potash, and from 0.03 to 0.04 per cent. of phosphoric". For some reason cacao does not appear to have been very successful in the Uva province, up to the present, some ascribing the poor crops obtained to the absence of pollinating agencies and others to the climatic conditions prevailing there. On many estates the soil is very rich in plant food and possesses excellent physical properties, but the yield of cacao obtained from mature trees is often less than two hundred pounds per acre, per year. Cacao is now being planted in the Uva Province in conjunction with Erythrina and rubber trees, and rarely as a single product.

Cacao Soils in the West Indies and America.

According to Hart, to whose book reference should be made for further details, the following are types of good and inferior cacao soils as determined in the Government Laboratory, British Guiana:—

Good Cacao Soils.

	Demerara.	Grenada.	St. Vincent.	Trinidad.	Nicaragua.	Surinam.
Organic matter and combined water ...	9·031	10·442	3·046	3·768	10·815	15·452
Phosphoric anhydride	0·087	0·184	0·114	0·084	0·293	0·139
Sulphuric anhydride...	0·018	traces	0·055	traces	0·141	0·047
Chlorine ...	traces	nil	traces	nil	0·007	traces
Iron peroxide ...	4·783	9·485	9·574	3·910	7·000	5·952
Alumina ...	9·217	10·024	8·889	2·038	4·717	16·976
Manganese oxide ...	0·347	0·313	0·435	0·127	0·163	nil
Calcium oxide ...	0·596	2·379	4·981	0·356	2·250	0·495
Calcium carbonate ...	0·032	0·026	nil	nil	nil	nil
Magnesium oxide ...	0·404	3·367	2·418	0·495	0·217	1·071
Potassium oxide ...	0·291	0·343	0·178	0·118	0·619	1·072
Sodium oxide ...	0·208	0·574	0·369	0·278	1·184	0·258
Insoluble silica and silicates ...	74·986	62·863	69·941	88·826	72·594	59·438
	100·000	100·000	100·000	100·000	100·000	100·000
1. Containing nitrogen	0·262	0·271	0·205	0·100	0·228	0·306
Water retained by air-dried soil ...	6·5	12·4	8·1	1.8	8·0	11·

Inferior Cacao Soils.

The following are examples of poor cacao soils, from which the yields are reported as being very unsatisfactory:—

	Demerara.	Surinam.	St. Vincent.	Grenada.
(1). Organic matters & combined water ...	Per cent. 4·471	Per cent. 18·701	Per cent. 3·029	Per cent. 12·897
Phosphoric anhydride	0·020	0·157	0·042	0·050
Sulphuric anhydride...	0·111	nil	0·045	0·099
Chlorine ...	nil	trace	trace	trace
Iron peroxide ...	4·081	3·874	9·695	22·349
Alumina ...	7·214	15·269	7·374	26·925
Manganese peroxide ...	0·005	nil	0·487	0·320
Calcium oxide ...	0·225	0·010	4·787	0·210
Calcium carbonate ...	nil	nil	trace	0·264
Magnesium oxide ...	0·041	0·661	1·899	0·314
Potassium oxide ...	0·051	0·041	0·083	0·056
Sodium oxide ...	0·225	0·003	0·704	0·230
Insoluble silica and silicates ...	83·556	61-284	71·855	36·286
	100·000	100·000	100·000	100·000
1. Containing nitrogen	0·057	0·265	0·075	0·171
Water retained by air-dried soil. ...	1·9	7·6	7·6	14·1

Soils in Venezuela and Trinidad*.

Composition of Air-Dried Soils.

	Trinidad. Per cent.	Venezuela. Per cent.
Water ...	3·66	10·74
Dry Soil ...	96·34	89·26
	100·00	100·00

Composition of Dry Soil.

	Trinidad.	Venezuela.
(1) Loss on Ignition ...	8·948	7·610
Iron Oxide ...	2·440	6·200
Alumina ...	5·313	—
Lime ...	0·148	0·594
Magnesia ...	0·284	0·782
Potash ...	0·217	0·392
Soda ...	0·142	0·177
Phosphoric Acid ...	0·116	0.147
Sulphuric Acid ...	0·025	0·036
Chlorine ...	0·093	0·016
Insol. Silicates ...	82·364	84·046
	100·000	100·000
(1) Containing Nitrogen	0·165	0·071
Equal to Humus ...	0·386	0·225
Nitrogen as Nitric Acid	0·00335	0·00636

Readily available Potash and Phosphates.

Potash ...	0·0881	0·1707
Phosphoric Acid ...	0·0465	0·082

* Hart, l. c. chapter 12.

Soils in Samo.

Though the soils in Samoa are largely of a volcanic origin and moderately fertile, their productiveness cannot be dissociated from the good and well-distributed rainfall and climate which prevail there. Some of the soils are very rich in iron compounds and appear to be deficient in other mineral constituents. Wohltmann* gives, among others, the following analyses made under the direction of Dr. Ehlert of soils in one part of Samoa, showing in each case the composition of the soil at different depths from the surface to 100 cm. (about 39½ inches):—

	Sample 1.				Sample 2.			
	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.
Depth of soil ...	0·25	25·50	50·75	75·100	0·25	25·50	50·75	75·100
	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent
Moisture ...	9·440	10·028	11·720	10·982	15·062	14·036	13·700	13·242
Ignition Loss (water and organic matter)	22·928	19·664	20·146	20·278	17·288	12·912	12·734	12·770
Nitrogen ...	0·348	0·144	0·146	0·115	0·447	0·177	0·189	0·186
Cold hydrochloric extract;								
Iron & alumina ...	32·711	36·730	34·905	36·253	27·221	30·203	29·604	30·870
Iron oxide ...	19·466	20·960	20·480	24·640	17·600	18·693	19·173	19·653
Alumina ...	13·245	15·770	14·425	11·613	9·621	11·510	9·431	11·217
Titanic acid ...	2·093	2·570	2·146	2·733	2·043	2·425	2·545	2·853
Lime ...	0·243	0·065	0·080	0·069	0·113	0·030	0·020	0·033
Magnesia ...	0·119	0·061	0·012	0·059	0·285	0·022	0·097	0·144
Phosphoric acid...	0·255	0·330	0·415	0·420	0·179	0·264	0·179	0·213
Potash ...	0·032	0·024	0·018	0·018	0·048	0·033	0·033	0·022
Hot hydrochloric acid ...								
Potash ...	0·096	0·085	0·046	0·042	0·077	0·055	0·044	0·043

If the reader desires further details reference should be made to Wohltmann's exhaustive paper on this subject. The nitrogen and phosphoric acid appear to be present in fairly good proportions, while the lime, magnesia, and potash are deficient. The iron content is abnormally high, and according to Wohltmann the same feature is observable in the soils of the Cameroon mountains, where as much as 12 to 15 and even 19 per cent. of iron oxide occurs in some of the basaltic rock soils. It is asserted that many of these soils can only be successfully cultivated if manuring is extensively adopted, though instances are known where crops have been grown on such soils for ten years without an application of potash or lime.

* Der Kulturwert der Samoa-Boden, by Prof. Dr. Wahltmann. Der Tropenpflanzer, December, 1902. p. 601.

CHAPTER XII.

THE CHEMISTRY OF THE CACAO TREE.

In compiling a complete account of the chemistry of various parts of the cacao tree it is necessary to know the age of all the parts analysed, the nature of the varieties, and the conditions of the plants and their environments. Leaves, or any other organs of the same cacao plant, have usually similar morphological characters, but a variation does occur, not only in the form and size but in the histology of outwardly similar members; such variations are founded on, or associated with, differences in the composition of the components of these structures. The variations which occur in the proportion and condition of the fibres of the cortex and wood, in the mineral constituents in the parenchymatous cells of vegetative and fruit structures, and in the proteid, carbohydrate, fatty, and other reserve substances in different parts of the plant are only too well known to microscopists.

It is almost impossible, even when the same variety of cacao is grown under what are considered to be similar soil and climatic conditions, to guarantee that seeds from the same fruit will produce plants with organs of equal vigour. The individual variation in the same cacao plant is very large, but falls into insignificance when one considers the differences between trees of the Criollo and Amelonado varieties, regularly pruned and unpruned trees, plants grown on alluvial flats and rocky hillsides, cacao trees five to twenty-five years old, or between healthy and well-manured as against diseased and impoverished specimens. This variation in original constitution and conditions is necessarily associated with differences in chemical composition; nevertheless, in the various analyses of parts of cacao from different parts of the world, there is often not only a general but a close agreement. The variations in chemical composition depicted in the comparisons of analyses given in this chapter are not exceptional, but they are sufficiently conspicuous to prevent anyone from calculating, to the required degree of accuracy, the quantitative loss of nitrogen and mineral constituents which accompany the cultivation of cacao; only very general conclusions can be drawn from the analyses given.

Chemistry of the Cacao tree.

Cockran, in his analyses of parts of the cacao tree, calculates that the stem and primary branches constitute 50·2 per cent., leaves and smaller branches 36·6 per cent., and the root tissues 13·2 per cent., and though his analyses show the average composition of material in this proportion, it must not be surmised that all trees have their parts in the above ratios. The percentage of organic

matter is highest in the seed, stem and primary branches, and lowest in the leaves and fruit walls; the percentage of nitrogen is highest in the seeds and lowest in the stem, while the ash constituents are lowest in the seeds, and reach their maximum in the leaves, small branches, and fruit walls.

Composition of the Ash of the Cacao Tree.

Cockran, after quoting the analyses given below, points out that the ash of all parts of the tree is particularly rich in potash, and that the ash of the fruit wall consists of nearly one half of potash.

	Root.	Stem and primary branch.	Leaves and smaller branches.	Seeds.	Pod-husks.
Silica and Sand ...	8·07	0·562	28·29	2·35	2·43
Lime ...	22·89	29·317	25·62	6·80	8·67
Magnesia ...	8·83	9·910	5·54	16·77	6·92
Potash ...	27·68	29·257	19·15	36·56	49·41
Phosphoric acid ...	3·01	4·237	3·33	30·80	4·43
Other Constituents	29·52	26·717	18·07	6·72	28·14
	100·00	100·000	100·00	100·00	100·00

Jumelle, page 88, gives the following analyses of parts of the cacao tree :—

Ash Analyses of a Cacao Tree 20 Years Old.

(Parts of the Plant.) Dried in air.	Ashes.	Phosphoric acid.	Potash.	Lime.	Magnesia.
Trunk. ...	4·53	0·198	0·83	1·56	0·29
Large branches ...	3·37	0·317	0·64	0·78	0·24
Medium ,, ...	4·33	0·509	0·77	0.82	0·26
Small ,, ...	7·04	0·566	0·58	1·67	0·32
Leaves ...	15·06	0·370	1·45	1·60	0·49
Seeds in the fresh state. ...	3·58	1·377	0·95	0·22	0·29
Shell in fresh state	4·56	0·409	0·80	0·49	0·16
Husks of fruit in fresh state ...	11·90	0·585	3·15	0·87	0·17
Pruned branches ...	8·97	0·830	0·71	1·12	0·34

Many similar analyses have been made by Harrison, Boname, and Marcano. Having shown the proportion of the various parts of the cacao tree to one another and their chemical ingredients we can now consider the quantity of chemical ingredients in the trees occupying an acre of land. The results of Marcano and Cockran are arranged in the following table :—

Composition of One Acre of Cacao Trees.

	Marcano. lb.	Cockran. lb.
Nitrogen ...	201 ...	123
Lime ...	400 ...	313
Magnesia ...	111 ...	86
Potash ...	251 ...	277
Phosphoric acid ...	95 ...	42

It is obvious from the above that the quantity of constituents in the trees referred to by Marcano in Venezuela and Cockran in Ceylon are widely different, but in both cases one can see that the proportion and importance of lime, potash, nitrogen, magnesia, and phosphoric acid form continuous series, the first-named being the most abundant and the last-named the least abundant constituent in the cacao trees on an acre of land. The quantitative differences in the above analyses are explained by the difference in age and size of trees in the two countries, and the inclusion of roots in Cockran's analyses.

Annual Soil Exhaustion.

The amount of ingredients removed annually by one acre of cacao depends upon the number and kind of trees per acre, the crop harvested, whether the husks are returned to the soil, and whether pruning is systematically adopted. In Ceylon, pruning of the cacao trees is not regularly carried on, but in many of the West Indian possessions the suckers, leaves, and twigs thus obtained are of importance, and the following analyses by Marcano* are of considerable value:—

Ingredients per Acre in Young Shoots, Suckers, and Leaves.

	Suckers and Young Shoots.	Leaves.	Total.
Nitrogen	84 lb.	39 lb.	123 lb.
Phosphoric anhydride ...	49 ,,	75 ,,	124 ,,
Potash	42 ,,	30 ,,	72 ,,
Lime	66 ,,	32 ,,	98 ,,
Magnesia	20 ,,	10 ,,	30 ,,

These prunings, obtainable on cacao plantations in the West Indies, must be somewhat bulky as the total of 123 lb. of nitrogen is exactly what Cockran calculated for one acre of living cacao trees in Ceylon.

Cacao Husks.

The husks of the cacao fruits are either returned to the soil or removed; in parts of Ceylon they are usually buried with lime in large pits, or burnt, and since nearly 50 per cent. of the ash consists of potash the application of the same to the soil should be advantageous. When the fruit walls are burnt there must be an irrecoverable loss of nitrogen, and for this reason burning need not be adopted except where it is necessary, for plant sanitation reasons, to do so. From a reference to the analysis by Cockran the composition of the fruit wall in Ceylon may be seen. According to analyses,† the return of these waste tissues to the soil reduces the exhaustion, due to the cacao crop, per acre per year, to 6·8 lb. of nitrogen, 3·4 lb. of phosphoric anhydride, 18·4 lb. of potash, 5·1 lb. of lime, and 1·3 lb. of magnesia on West Indian cacao estates. In the West Indies the fruits

* Essais d' Agronomie Tropicale, V. Marcano. † Hart, l. c.

from one acre of cacao in bearing are supposed to remove, annually, 15·5, 7·9, 22·1, 6·5, and 2·3 lb. of these ingredients respectively, providing seeds and husks are entirely removed.

Weight of Ingredients Annually Required.

On an ordinary estate, the weight of ingredients annually required by the cacao trees will show great variations according to the methods of cultivation and the crop harvested. A large quantity of leaves are normally shed, which, if properly dealt with, represent very little loss to the soil; the increased root, stem, and leaf tissues, and the seeds or fruits removed, represent more exactly, what is annually removed from the soil. According to Harrison the yearly production of young shoots, leaves, and fruits on each acre requires 138 lb. of nitrogen, 64 lb. of phosphoric anhydride, 94 lb. of potash, 104 lb. of lime, and 31 lb. of magnesia. The greater part of these constituents are, however, under good cultivation, available as plant food at a subsequent date when the decomposition of the leaves, prunings, and fruit walls has been completed. Taking into consideration the materials required for the incremental development of all parts of a cacao tree and the removal of seeds only, Cockran calculated that one acre, containing 302 cacao trees, in Ceylon, giving 1 lb. of cured cacao and 1·26 lb. of dry pods, per tree, would remove the following from the soil, annually:—

Weight of Ingredients Annually Removed.

	Increment of parts of Cacao tree.	Increment & crop of cacao seeds.	Increment & crop of cacao seeds & fruit walls.	Amounts removed in seeds & fruit walls.
Nitrogen	24.6 lb.	31.5 lb.	36.9 lb.	12.3 lb.
Lime	62.7 ,,	63.4 ,,	66.8 ,,	4.1 ,,
Magnesia	17.3 ,,	19.0 ,,	21.7 ,,	4.4 ,,
Potash	55.5 ,,	59.3 ,,	78.3 ,,	22.8 ,,
Phosphoric acid	8.4 ,,	11.7 ,,	13.4 ,,	5.0 ,,

The relative importance of potash, nitrogen, and phosphoric acid is therefore manifest in the West Indian and Ceylon analyses.

Jumelle gives a very complete table showing the demand which the branches, leaves, seeds, and fruit walls make upon the soil. The quantities of nitrogen and ash constituents required, per hectare, and per 70 acres of cacao, are given for each part of the tree when in bearing. In this table the quantity of ingredients required form a series, with lime greatest in demand, then potash, nitrogen, phosphoric acid respectively, and finally magnesia the least important.

Relative Importance of Essential Ingredients.

If these results are compared with those of Cockran one will notice that they agree in respect of the lime, potash, and nitrogen required for the incremental growth and crop of cacao seeds, but if the fruit walls be also taken into consideration the potash

removed is greater than the lime. Both series of analyses are probably correct and applicable to Ceylon; Jumelle, in giving the order of quantites demanded by all parts of the tree on a cacao plantation, places the ingredients in the following order:—Lime, potash, nitrogen, phosphoric acid, and magnesia; Cockran only calculates what is removed from the soil by incremental growth and cacao seeds, the order being lime, potash, nitrogen, magnesia, and phosphoric acid, but if the fruit walls are included then the quantitative order is changed to potash, lime, nitrogen, magnesia, and phosphoric acid. It is important to notice the relative importance of magnesia and phosphoric acid displayed in Cockran's analyses, as one would normally expect phosphoric acid to be the more important ingredient in fruit cultivation. All the analyses agree in so far that they indicate the importance of lime for building up all parts of the tree, and in giving potash and nitrogen important but less essential positions for the purpose.

On cacao estates with mixed varieties the proportion of the ingredients removed will vary considerably, for as shown elsewhere the composition of the Forastero and Calabacillo varieties is different in respect to the nitrogen, potash, phosphoric anhydride, and other ingredients. "The fruit of Calabacillo* contained less water but distinctly more nitrogen, potash, and phosphoric anhydride than that of Forastero. The kernels of the beans of Calabacillo were distinctly richer in the alkaloids, also in astringent matter and in cacao-red than were those of Forastero, the result being that the beans of the former variety were of a harsher, more astringent flavour than those of the latter. The beans of the two varieties showed but little difference in their contents of fat, but those of Forastero were of higher contents of starch and sugars. In the cuticles and pulp from Calabacillo there were found somewhat lesser amounts both of the alkaloids and of starch and sugars than in those from Forastero. In the husks of both varieties small amounts of theobromine—less than one per cent. were found—but no caffeine, which was present in small quantities in the kernels and cuticles of both varieties, was found in either. But little difference existed in the husks of both varieties in their contents of nitrogen and phosphoric anhydride, but those of Calabacillo contained the higher proportion of potash. When, however, the higher proportions of husk in the fruit of Forastero are taken it appears that this variety returns more nitrogen, more phosphoric anhydride, and but little less potash to the soil in the waste husks than those in an equal weight of the fruit of Calabacillo. But it requires double the weight of fruit of Forastero than of Calabacillo to produce an equal weight of cured cacao, hence the return to the soil by the husks is more than twice as great in the case of the former than that of the latter."

Investigations in the West Indies.

In all countries the seeds are always removed, and as the exact weight of the crop is known, a definite statement of the loss to the

* Harrison, l.c.

soil can be obtained. The composition of the different varieties of cacao in Venezuela, Guadeloupe, Trinidad, British Guiana, and Ceylon have been determined by Marcano, Bonamie, Harrison, Cockran, and others, and the following very complete analyses will be of value in discussing this part of the subject.

The fresh pods were found, by Harrison, to yield as follows :—

	Calabacillo.		Forastero.
Husk ...	... 80.59	...	89·87
Pulp ...	... 7.61	...	4·23
Cuticles of Beans	... 1·77	—	0·50
Kernels of Beans	... 10·03	—	5·40
	100·00		100·00

"The yields of cured cacao are 37·5 and 35·6 per cent. of the beans and pulp of the two varieties respectively. Hence 100 lb. of the fruit of Calabacillo will yield 7·25 lb. of fermented cured cacao and 100 lb. of the fruit of Forastero 3·6 lb. There would appear to be a distinct advantage in growing cacao of the variety Calabacillo; but the difference in the market value of the small flat brands of this variety and in that of the large plump beans of Forastero very materially reduces the apparent advantage while comparatively upon light soils of higher elevation the agricultural yield of Calabacillo is frequently less than that of Forastero." In the following tables several organic constituents have been left out of Harrison's original analyses.

Constituents of the Various Parts of the Cacao Fruit, Variety "Calabacillo."*

	Kernels of beans.	Cuticles and pulp.	Husks.
Water	37·637	87·600	82·893
1. Albuminoids	6·696	·918	0·760
2. Indeterminate nitrogenous matters.	0·531	traces	0·169
Fat	29·256	0·444	0·146
Glucose	0·991	0·725	0·132
Sucrose	traces	0·066	traces
Starch	3·764	0·945	0·469
Iron peroxide	0·032	0·004	0·005
Magnesia	0·324	0·114	0·099
Lime	0·054	0·054	0·039
Potash	0·142	0·190	0·454
Soda	0·239	0·041	0·041
Silica	0·016	0·002	0·006
Sulphuric anhydride	0·079	0·021	0·042
Phosphoric anhydride	0·749	0·115	0·082
Chlorine	0·019	0·018	0·036
1. Contains nitrogen	1.071	0·147	0·121
2. ,, ,, ...	0·416	0·077	0·029
3. ,, ,, ...	0·031	0·012	nil
4. ,, ,, ...	0·085	nil	0·027
Total nitrogen. ...	1·603	0·236	0·177

* Harrison, l.c.

CONSTITUENTS OF THE VARIOUS PARTS OF THE CACAO FRUIT VARIETY "FORASTERO."*

	Kernels of beans.	Cuticles and pulp.	Husks.
Water	36·567	83·030	84·538
1. Albuminoids	4·826	1·271	1·017
2. Indeterminate nitrogenous matters.	2·725	nil	0·031
Fat	30·602	0·421	0·142
Sucrose	0·165	1·001	0·969
Glucose	0·917	0·091	nil
Starch	6·038	1·305	0·445
Iron peroxide	0·032	0·010	0·009
Magnesia	0·454	0·073	0·101
Lime	0·105	0·030	0·037
Potash	0·635	0·248	0·358
Soda	0·068	0·015	0·073
Silica	0·016	0·003	0·008
Sulphuric anhydride	0·048	0·031	0·032
Phosphoric anhydride	1·045	0·098	0·096
Chlorine	0·032	0·061	0·026
1. Containing nitrogen	0·772	0·203	0·163
2. ,, ,, ... —	0·436	nil	0·005
3. ,, ,, — ...	0·271	0·107	0·030
4. ,, ,, — ...	0·064	0·017	nil
Total nitrogen. ...	1·543	0·327	0·198

* "Assuming that the average yield of the variety Calabacillo is 250 lb. and that of Forastero 150 lb. of cured cacao per acre respectively, it will be seen that the amount of the constituents of plant food removed from the land annually in the whole fruit, returned to the soil in the husks, and either sold in the cured cacao or lost in the sweatings from the fermenting boxes is as follows":—

POUNDS PER ACRE PER ANNUM.

Variety of Cacao.	Calabacillo.			Forastero.		
Parts of fruit referred to.	Whole fruit	Refuse husk	Beans & pulp.	Whole fruit	Refuse husk	Beans & pulp
Weight per acre ...	6,200	5,000	1,200	6,900	6,200	7·00
Nitrogen ...	20·15	8·85	11·30	19·04	11·78	7·26
Phosphoric anhydride ...	9·42	4·10	5·32	10·14	5·95	4·19
Potash ...	29·01	22·70	6·31	25·39	22·19	3·20
Lime ...	2.60	1·95	·65	2·76	2·29	0·47
Magnesia ...	7·44	4·75	2·69	8·21	2·66	1·95

ANNUAL UNAVOIDABLE LOSS.

The unavoidable loss per acre in Demerara, British Guiana,† taking the crop of cured Calabacillo at 250 lb. and the Forastero at 150 lb., as compared with that in Venezuela given by Marcano

* Hart, Chapter 12.
† Proceedings of the Agr. Soc., British Guiana.

and with that in Guadeloupe yielding 450 lb. per acre reported by Boname, is as follows:—

POUNDS PER ACRE PER ANNUM.

	Demerara.		Venezuela.	Guadeloupe.
	Calabacillo.	Forastero.	Varieties not stated.	
Nitrogen ...	11·30	7·26	7·8	7·3
Phosphoric anhydride	5·32	4·19	4·5	2·8
Potash ...	6·31	3·20	3·7	4·3
Lime ...	0 65	0·47	1·4	0·4
Magnesia ...	2 62	1·95	1·0	1·4

There is a general concordance in these results showing the low amount of constituents necessarily removed from the soil in the production of a crop of cacao.

ANALYSES OF CACAO NIBS:

CEYLON-GROWN CACAO.

	Amelonado.	Caracas.	Forastero. (Cundeamor).
	Per cent.	Per cent.	Per cent.
Moisture	4·75 to 4·90	4·20 to 5·40	4·50 to 6·50
Ash	3·26 to 4·09	3·64 to 3·72	3·76 to 3·92
Fat	43·45 to 54·40	42·54 to 51·40	44·12 to 52·50
Fibre	2·42 to 9·62	2·34 to 9·62	2·42 to 6·44
Proteids	13·25 to 13·56	12·12 to 13·13	12·37 to 12·81
Alkaloids	0·72 to 0·86	0·68 to 1·16	0·54 to 1·04
Carbohydrates and etc.	19·77 to 24·95	22·67 to 27·20	20·81 to 28·27
Total Nitrogen ...	2·32 to 2·41	2·13 to 2·46	2·13 to 2·35

The above analyses, by Bamber and Bruce placed before the Committee of Agricultural Experiments, Peradeniya, by Mr. M. Kelway Bamber, show the range in composition of certain samples of fermented and cured cacao nibs, grown at the Experiment Station Peradeniya.

CHEMISTRY OF CACAO SEEDS: CACAO SEEDS FROM PORTUGUESE-CONGO.

The following analyses of seeds from Cabinda, Portuguese-Congo, have been made by Silva,* and Fonseca:—

	Per cent.
Moisture	8·40
Albumen	11·37
Fat	36·80
Sugar	0·58
Starch	23·09
Raw Cellulose	4·24
Theobromine	1·09
Caffeine	0·47
Ashes	2·00
Other substances	11·96
	100·00

* Analyse des Kakao von Cabinda, Der Tropenpflanzer, Vol. VI., 1902.

Moller † states that in comparison with other seeds the proportion of fat was as great as with Trinidad, Surinam, and Guayaquil, while Para even showed a lower percentage than the above; the ashes of most other cacaos are usually more abundant than in the above sample, the average range being, according to Moller, from 2·92 to 3·03 per cent. The percentage of Theobromine in this sample is relatively high.

Analyses of Samoan Cacao.

Wohltmann, in Der Tropenpflanzer for 1902, gives the following interesting analyses of cacao kernels and integuments from Samoa:—

100 Cacao beans weighed	=	66·4 grams.	
Integuments ,,	=	59·2 ,,	equal 89·15 per cent.
Kernels ,,	=	7·2 ,,	,, 10·85 ,,
Ash of kernels ,,	=	2·842 per cent.	
,, ,, integuments	=	5·794 ,,	,,

	Ash.	
	Kernels	Integuments.
	Per cent.	Per cent.
Potash ...	... 34·84	... 41·57
Soda ...	... 1·94	... 2·18
Lime ...	... 5·19	... 7·95
Magnesia ...	... 16·15	... 17·18
Iron oxide ...	... 0·88	... 2·53
Phosphoric acid	... 37·53	... 19·80
Silica ...	... 0·64	... 1·97

The above analyses show a somewhat higher proportion of potash in the kernels and integuments than has been accepted as the average for cacao. The importance of potash is manifest in these as in most other analyses.

Chemistry of Commercial Samples of Cacao.

In addition to the analyses by Harrison, Bamber, Wohltmann, and Silva, others have been made of cured cacao from various countries by Zipperer, Lampardius, Muter, Mitscherlich, Boussingault, Payen, Playfair, and Lankester. In the table of analyses given below, showing the chemical composition of the kernels of cured cacao from different countries, it is shown that a considerable variation exists in the percentage of some of the most important items affecting their commercial value; for instance the cacao butter varies from 42 to 53·66 per cent., and albuminous materials from 10·9 to 21·45 per cent. The range in the proportion of the fatty, starchy, nitrogenous, alkaloid, and astringent substances are worthy of consideration.

† Der Tropenpflanzer, l. c.

Analyses of the Kernels of Cured Cacao.*

	Lampardius.	Payen.		Playfair & Lankester.	Boussingault.		Mitscherlich. (Guayaquil.)	
Water ...	5·20	10·00	12·00	5·00	11·60	7·60	5·06	6·30
Cacao butter ...	53·10	48·00	50·00	50·00	53·30	49·90	45·00	49·00
Albuminoid substances ...	18·70	21·00	20·00	20·00	12·90	10·90	13·00	18·00
Starch & traces of Sugar ...	10·91	11·00	10·00	7·00	6·70	2·40	14·60	18·00
Gums ...	7·75	—	—	6·00	—	2·40	—	—
Cellulose ...	—	3·00	2·00	—	9·10	10·60	6·08	—
Woody fibres ...	0·90	—	—	4·00	—	—	—	—
Theobromine ...	—	4·00	2·00	2·00	2·40	3·30	1·02	1·50
Cacao-red ...	2·01	—	—	2·00	—	—	3·05	5·00
Tannins, etc. ...	—	—	—	—	—	0·20	—	—
Mineral matter ...	—	3·00	4·00	4·00	4·00	4·00	5·05	—
Tartaric acid ...	—	—	—	—	—	3·40	—	—
Other substances ...	1·43	—	—	—	—	5·30	9·14	—
Total ...	100·00	100·00	100·00	100·00	100·00	100·00	100·00	97·80

	Muter.	Zipperer.						
		Ariba.	Guayaquil.	Caracas.	Puerto-Cabello.	Surinam.	Trinidad.	Port-au-Prince.
Water ...	5·98	8·35	6·32	6·50	8·40	7·07	6·20	6·94
Cacao Butter ...	42·67	50·39	52·68	50·31	53·01	50·86	51·57	53·66
Albuminoid substances ...	12·21	19·44	12·04	17·23	13·31	21·45	15·79	13·28
Starch and traces of sugar ...	19·03	5·78	8·39	7·65	10·05	6·41	11·07	8·96
Gums ...	6·40	—	—	—	—	—	—	—
Cellulose ...	5·95	2·66	2·41	2·61	2·52	2·68	2·64	2·53
Woody fibres ...	—	—	—	—	—	—	—	—
Theobromine ...	0·90	0·35	0·33	0·77	0·54	0·50	0·40	0·32
Cacao-red ...	5·90	8·91	13·72	10·76	7·85	8·31	9·46	11·39
Tannins, etc. ...	—							
Mineral matter ...	3·96	4·12	4·11	4·17	4·32	2·72	2·87	2·92
Tartaric acid ...	—	—	—	—	—	—	—	—
Other substances ...	—	—	—	—	—	—	—	—
Total ...	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00

Physical and Chemical Characters of Cacao Components.

Alkaloids.—These highly complex organic compounds are responsible for the stimulating effect of cacao, and the analyses published by Harrison show that theobromine and caffeine may be present, the former varying from 0·3 to 4 per cent. and the latter

* Le Cacaoyer, Jumelle, page 47.

occurring in very small proportions. According to Jumelle, theobromine crystallises in anhydrous prisms, is bitter to the taste, partially soluble in boiling water, readily soluble in ammonia, but insoluble in benzine. The caffeine is obtainable from the cacao in the form of long needle-like crystals which melt at high temperatures.

Starch and Sugars.—These form as much as 19 per cent. of some specimens of cacao and only 6 per cent. of others, and in order of quantity come next to the cacao butter and albuminous matters. The starch grains are abundantly distributed through the substance of the cotyledons, and occur in groups of three or four very small grains. Application of an ethereal tincture of iodine to a section of the bean turns the starch grains deep blue; the striations on the starch grains are usually very indistinct. During germination much of the starch is converted into sugar to be used by the young plant.

Albuminous Matters.—These form, next to the fats, the most abundant constituents of cacao beans—about 20 per cent.—and are of a very complex nature.

Cacao Butter.—From the foregoing analyses it is obvious that nearly half the total weight is made up of fatty substances. Cacao butter is a solid substance at ordinary temperatures, but according to Jumelle begins to soften at 25°C.; it is readily broken, sweet in taste, and of a bright yellow colour. The specific gravity varies from 0·945 to 0·982 according to age. The fatty substances may consist of oleine, stearine, palmitene, laurine, and free fatty acids, and are mostly soluble in ether, but not in cold alcohol. These mixed substances melt at temperatures varying according to their proportion; the adulteration of cacao butter may be detected by determining the difference between the melting points of the pure butter and the substances under examination, though the accuracy of this method is doubted by many.

The butter from cacao beans may be extracted by steaming the finely-divided kernels and pressing the same between hot plates of metal, or by making the kernels into a fine paste and after adding boiling water pressing it between hot plates; the material to be pressed should be put in muslin or cotton bags so as to effect filtration as the oil oozes out.

The mineral substances are particularly rich in phosphoric acid, potash, and magnesia, and may form from 3 to 4 per cent. of the cured substance of the kernels. The cacao-red is a colouring matter present in the kernel which with the theobromine gives to cacao its characteristic taste; it is the cause of the red colour, and can be obtained by precipitation from the aqueous extract by acetate of lead.

Chemical Tests for Varieties of Cacao.

A considerable amount of work has been done by Trojanowsky and Jumelle to determine whether the different cacaos can be

identified by means of chemical tests. The kernels of different varieties were powdered and mixed with a definite proportion of sugar and distilled water and, after filtering, the filtrate was divided into many portions and each treated with a specific reagent. The colour of the precipitate, if any appeared, and that of the solution, were considered to indicate the variety of cacao under examination; by means of solutions of nitrate of copper, nitric acid, nitrate of silver, chloride of zinc, chloride of mercury, and other reagents it was hoped to distinguish between the Caracas, Surinam, Trinidad, Guayaquil, Ariba and other cacaos, according to the colour reactions and nature of the precipitates produced. In some cases the tests appeared to be useful, but in most instances they could not be recommended as reliable.

Experience on an estate where cacao is grown will convince anyone that the physical and chemical constitution of the same variety of cacao is liable to a considerable amount of variation, according to the nature of the soil, the age of the trees, and their condition of vigour. In any one country where cacao has been long cultivated, different seeds in the same fruit from a Caracas, Nicaraguan, or Forastero tree vary to an extent which is often surprising. The cacao exported from any district is comprised of seeds from innumerable varieties, and although that from each country may tend to become more or less uniform year by year, the variation during a single year or in successive years must be sufficiently great to seriously affect the value of a chemical test as a means of determining the actual variety or the country of export.

It is hard enough to identify all the varieties on an estate even when leaves, flowers, fruits, and seeds are at hand, and it must be much more difficult to determine constant chemical characteristics for the ever-changing forms of cacao under cultivation. Tests which are based on colour reactions or which are more or less equalitative do not appear to be reliable except in a very general way, though there seems to be no reason why different cacaos should not be recognised by the percentage of food constituents they possess, providing a very large number of quantitative analyses and practical experiments are carried out with carefully selected seeds of known or constant varieties. It does not require much imagination to conceive that seeds of that variety so constant in Ceylon—the Amelonado—may show constant differences in percentage of food constituents when compared with the variable seeds of Caracas or Forastero varieties.

CHAPTER XIII.

CACAO MANURES AND MANURING.

THE accurate determination of the individual or comparative value of manures for cacao is difficult and, very frequently, from long series of experiments, only a general conclusion can be arrived at. The problem is a complex one and necessitates a knowledge of the available food supplies in the soil and plant tissues both before and after the application of the manure, which our chemical and botanical methods do not supply except in an approximate manner; it involves the tracing of the original and subsequent soil constituents and of the manure applied through all parts of the plant and in the drainage water, and also the differentiation between the effect of the manure and that of the increasing age of the tissues bearing the cacao fruits. Each variety has to be studied separately and every allowance made for the difference in age, the nature of the ancestors, history of the plant from the embryonic stage, the variation in soil composition, and many other important details. It is, however, possible to make a few general statements regarding the effect of manures on cacao in various parts of the tropics, and to at least distinguish between bad and good methods of cultivation, and between manures having positive and negative effects.

Effect of Manures.

It has been shown elsewhere that the cacao bean or seed is rich in the mineral constituents potash, phosphoric acid, lime, and also in nitrogen, and it will be of interest to consider the effect of manures containing one or more ingredients. Cacao grown in soils poor in one or more ingredients may naturally be expected to show improvement when the respective deficiencies are supplied as manure, and even in well-balanced soils the application of further supplies of food is often followed by a better development of one or more parts of the plant. It is conceivable that the application of manure to soils containing abundance of plant food may lead to an abnormal absorption and to a loss of equilibrium on the part of the plant: an application of a large excess of manure rich in readily available phosphoric acid was, in one case, followed by complete and rapid defoliation, the tree becoming almost leafless in about ten days; but it subsequently acquired new foliage, and is today perfectly healthy and bears large crops of fruit annually. But few soils in the tropics which have been under cacao cultivation for a few years are so rich as to be able to produce the best crops without artificial aid, and it is generally

accepted that the supplying of plant food is conducive to better and more rapid development of the plants, and is in most cases essential.

Methods of Manuring.

The methods of manuring cacao depend upon soil conditions, the varieties cultivated, and the age and periodicity of the trees under consideration. In most parts of the tropics manuring operations consist of hoeing or forking in organic matter or artificial manures during certain periods of the year, the execution of the work being usually determined, in time and thoroughness, mainly by the exigencies of the labour available, rather than by the requirements of the different varieties of plants or their parts.

Forking and Bacteria.

In Ceylon good results have been obtained by annually forking the whole of the soil on estates where the cacao trees are in bearing, during the wet season, or by performing this operation in and just beyond the root area of trees under three years of age. The bacteria responsible for the liberation of much plant food are increased by good and judicious forking, as this operation loosens the baked and trampled hard soil and allows free access of air and water; the larger the number of these microscopic organisms in the soil, the more fertile the latter will be. The influence of sufficient air and water on the development and rapid multiplication of what are termed the aërobic bacteria has been frequently demonstrated and their distribution in the soil, from the surface to a depth of two feet, appropriately illustrates this consideration. Chester* has shown the number of bacteria in different depths of soil, at the Experiment Station Grounds, Newark, Delaware, and from his figures the following table is drawn up:—

Proportionate Number of Bacteria from the Surface to Two Feet.

Depth of Soil.					Number of Bacteria.
Two	inches	...	...	...	981,000
Four	,,	...	...	...	1,632,000
Six	,,	...	...	...	1,623,000
Twelve	,,	...	...	...	73,000
Eighteen	,,	...	...	...	21,000
Twenty-four	,,	...	...	...	4,000

The results obtained by Chester may be briefly given as follows:—(1) "Numbers of bacteria in soils become an index of active fertility; (2) the combined effect of cultivation is to increase the number of bacteria in the soil, thus in turn setting free an increased quantity of available plant food." This increase in the number of food-liberators is accomplished by loosening the soil by forking only, and it may justly be concluded from this and other considerations that the performance of this operation is to be recommended over the root area of the cacao, without much destruction to the roots,

* F. D. Chester, Bacteria of the Soil in their Relation to Agriculture Bul. 98, Dep. of Agr., Commonwealth of Pennsylvania, 1902.

and to a depth of four to six inches. The bacteriology of the soil in the tropics is a science which, for unaccountable reasons, has been almost entirely neglected and our ideas are based mainly on results obtained elsewhere.

Application of Natural and Artificial Manures.

For obvious reasons the broadcasting of manures over mature cacao plantations, instead of burying them in deep local holes, is generally to be preferred, as the soil is better aërated and all parts of the root system have a chance to develop and absorb the food applied. The incorporation of all particles of the manure with the finely-divided soil should be accomplished even with bulky manures such as leaves, excreta of animals, etc.; readily soluble manures such as nitrates, phosphates, and potassic manures should, prior to being broadcasted, be throughly mixed with dry earth in order to ensure a better distribution—the increased volume being applied to greater effect.

Time and Method of Application.

The greatest importance should be attached to the time of application, this being determined by the solubility of the manure and the periodicity of the climate and plant. The results of experiments suggest that manures such as potasssium chloride, sodium nitrate, ammonium sulphate, and others are absorbed within a few days of their application, providing climatic and soil conditions are favourable; other readily soluble manures such as potassium sulphate and certain phosphates do not appear to act so rapidly, and others such as steamed bone dust, castor cake, rape cake, leaves and cattle manure, etc. only seem to have pronounced effects after several weeks or months; hence the lasting effect of manures of the latter class.

In a general way it may be stated that artificial and natural manures should be applied after the heavy rains, though the stable forms, if applied alone, do not appear to lose much when forked in thoroughly during the rainy season. A method of application, in which the stable manures alone are applied and the land forked in the wet season, and where the readily soluble artificial manures are broadcasted subsequently, without forking in the dry season, has found favour with many planters; such a method makes it possible for the plant, during its period of active growth, to draw upon all the manurial constituents more or less at one time, instead of on individual ingredients in their order of solubility. Most cacao planters, however, do not resort to the divided application, but usually fork in all the manure to be applied at one time of the year.

Manuring and Foliar, Floral, and Fruit Periodicities.

Ideal manuring operations cannot, however, be carried out without reference to the periodicity of parts of the plant. At Peradeniya it has been shown that there is first a period of special foliar activity in February and March, then one of rootlets and

flowers in April, May, and June, followed by a setting of the young cacao fruits in August; these are the important stages upon which depend the immediate and future crops of mature fruit. The dividing of the readily soluble manures into three parts, to be applied during the three periods of activity enumerated, or the application of the stable manures in January to March, and the subsequent broadcasting of the soluble manures in the two succeeding periods of activity, has been accompanied by satisfactory results, detailed in another part of this book. It is a system of manuring which ensures the minimum waste of manure and the supplying of food, in an available form, at a period when new tissues most require it; though it has not yet become largely known or adopted, it is one which has aroused interest among many persons.

The manures should, whenever possible, be applied in the vicinity of the feeding rootlets and not beyond the last formed slender roots or too near the bulky, woody roots at the base of the stem.

Relation of Dried Pods to Manurial Experiments.

The dried pods have, as far as possible, been regularly collected at Peradeniya. The tables, giving the progress and composition of the cacao crop for 1902-1906, show that the months of May and July may be responsible for many dried pods, mainly young and small, and associated with the flower activity for the same month. The months of August and September are also remarkable for the large number of dried pods, many of which have attained a considerable size, and must have been two or three months old when picked. During these months the "setting" of the pods is conspicuous, and in the very wet weather the number of pods which turn yellow and commence to shrivel is surprisingly large. It is possible that one of the causes of the pods drying up may be lack of nutrition, and in order to prevent or reduce the number of fruits of this class the application of readily soluble manures should probably be made during May or August. It has been shown previously that the dying back of the young fruits may be affected by diseases and ineffective pollination, in addition to lack of nutrition.

Manuring in Ceylon.

In Ceylon a fair amount of artificial and green manuring is adopted by cacao planters, though owing to other matters manuring does not appear to have received the attention it deserves. Results have been obtained at Peradeniya, and elsewhere will be found the yields obtained with organic, potassic, phosphatic, nitrogenous, and lime manures, on various experimental plots during the years 1902-1906.

Natural and Artificial Manures.

In dealing with this subject one must not lose sight of the fact that in cacao cultivation unlike that of tea, cinchona, coffee, coconuts, etc., a very large quantity of leaves are annually shed from the cacao trees which, together with those from the accompanying

weeds, shade and wind-belt trees, supply large quantities of organic matter and mineral constituents to the soil. In some countries the leaves and weeds form the principal manure for cacao, and it is therefore necessary to deal with them while discussing this subject. For our purposes the manures may be grouped into (1) natural, and (2) artificial manures, the former comprising those available from plants and animals on cacao properties, and the latter those sold by manure merchants.

Natural Manures: Leaves of Cacao, Shade Trees, and Herbaceous Plants.

Natural manures may be divided into (a) plant, and (b) animal manures, the former being obtained from the plants usually cultivated or allowed to grow on cacao land, and the latter from cattle, pigs, horses, etc. They naturally differ from the artificial manures in so far that they are less concentrated and usually contain all the ingredients required by growing plants in a form not as readily available as in those belonging to the artificial class.

Natural Plant Manures.—The leaves of the cacao tree are the most common of these manures in all cacao-growing countries. The foliage shows a nett increase year by year until maturity, but during that period and after there is a more or less regular fall of old leaves and a production of new taking place. The dried leaves of certain varieties of cacao in Ceylon contain 1 to 2 per cent. of lime, 1·3 to 1·8 per cent. of potash, 0·5 to 0·6 per cent. of phosphoric acid and about 2 per cent. of nitrogen. The comparative value of leaves from three varieties of cacao, as determined by Mr. M. Kelway Bamber, * is shown in the following list:—

Analyses of Cacao Leaves in Ceylon.

	Caracas or Criollo.		Forastero.	
	Air-Dried Sample.	Sample Dried at 100°C.	Air-Dried Sample.	Sample Dried at 100°C.
	Per cent.	Per cent.	Per cent.	Per cent.
Moisture ...	10·00	—	12·00	—
Organic Matter ...	80·16	89·07	80·44	91·41
Ash ...	9·84	10·93	7·56	8·59
	100·00	100·00	100·00	100·00
Ash containing:—	Per cent.	Per cent.	Per cent.	Per cent.
Lime ...	2·24	2·50	1·01	1·14
Magnesia ...	1·04	1·15	0·94	1·06
Potash ...	1·33	1·47	1·81	2·05
Phosphoric acid ...	0·51	0·56	0·64	0·72
Organic Matter containing:—				
Nitrogen ...	2·21	2·47	2·17	2·47

* Committee of Agr. Expts., Peradeniya, 1906.

Analysis of Amelonado Leaves.

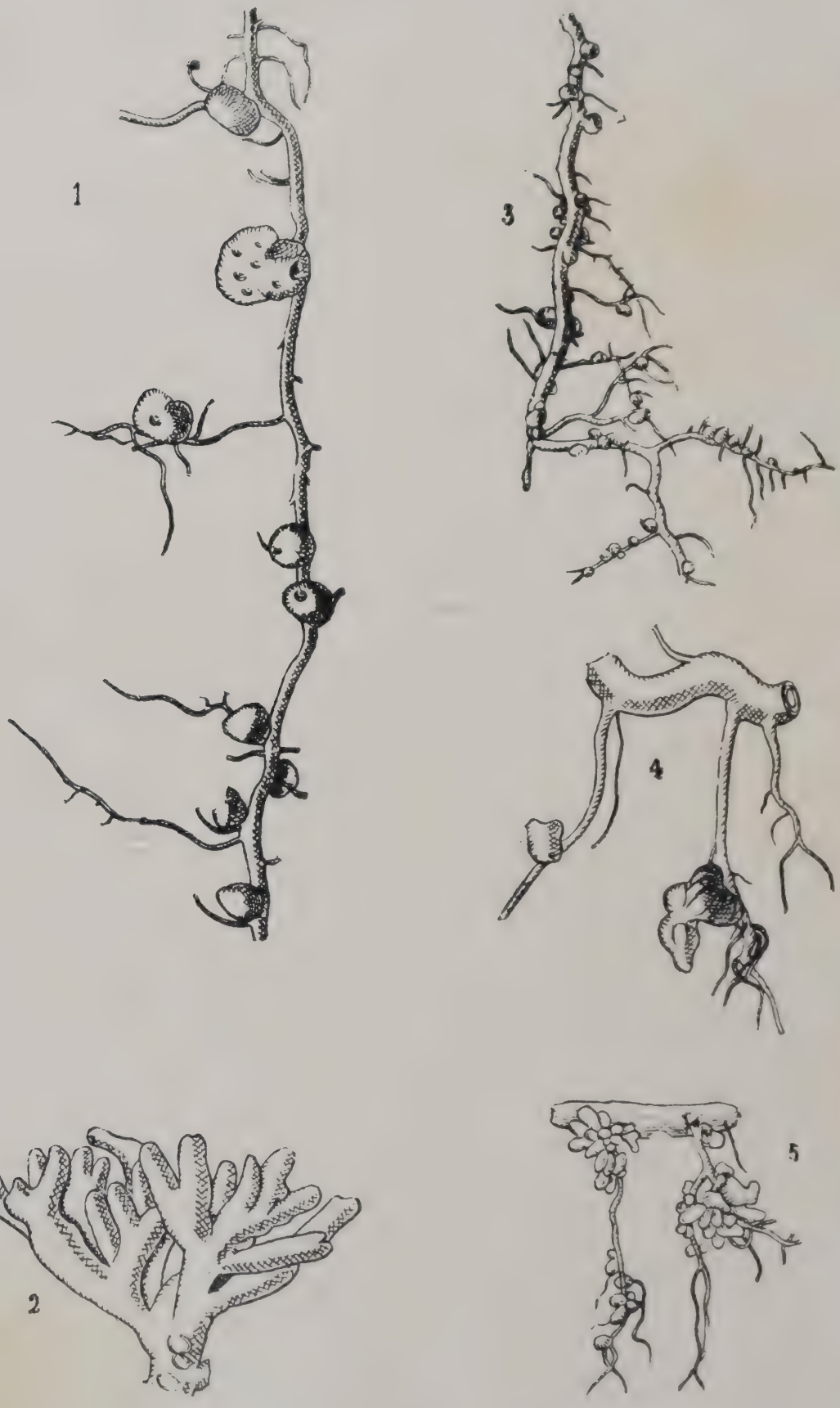
	Air-Dried Sample.	Sample Dried at 100°C.
	Per cent.	Per cent.
Moisture ...	10·00	—
Organic Matter ...	81·78	90·99
Ash ...	8·22	9·01
	100·00	100·00
Ash containing :—		
Lime ...	1·68	1·86
Magnesia ...	1·08	1·20
Potash ...	1·39	1·54
Phosphoric Acid ...	0·47	0·52
Organic Matter Containing :—		
Nitrogen ...	2·26	2·51

It is hardly necessary to point out that the above analyses should not be regarded as showing the constant differences between the leaves of different varieties of cacao or the constant composition of the same varieties in different countries; they are only quoted to show the probable range in composition and to provide a basis on which the manurial value of the fallen leaves may be calculated.

The weight of fallen leaves, per acre, per year, is difficult to determine accurately as it is influenced by the variety under cultivation, the amount of pruning which is carried out, the age of the trees, the periodicity of the local climate and leaf-fall, and the protection afforded by aspect, wind, etc. A few general experiments in Ceylon have indicated that the weight of fresh cacao leaves per 300 trees is approximately one ton. One plot of land, an acre in extent, which was thoroughly forked in January and all the leaves of cacao and shade trees then incorporated with the soil, had a layer of leaves on the soil in September, weighing 2 tons, 2904 lb. being dry dadap leaves, and 1563 dry cacao leaves. The soil is usually covered with a thick layer of these leaves at the end of the dry season, but on the arrival of the rains in April and June they are speedily decomposed.

Leaves from other Trees.

The leaves of shade trees and wind-belt trees probably come next in importance as they are cultivated in conjunction with cacao in many parts of the tropics. In Ceylon the shade trees which have been largely used are *Erythrina umbrosa*, *E. lithosperma*, *E. indica*, and occasionally *E. velutina*, *Albizzia moluccana*, *Pithecolobium saman*, *Hevea brasiliensis*, *Castilloa elastica*, *etc.* The boundaries of many cacao properties in Ceylon are also frequently planted with trees of *Eriodendron anfractuosum* and *Bombax malabaricum*—which annually pass through a leafless state of



NITROGEN BACTERIA AND ROOT NODULES.

Root nodules of (1) Erythrina lithosperma ; (2) Albizzia moluccana ; (3) Arachis hypogœa ; Vigna sps. ; (5) Crotalaria striata.

several weeks' duration—and with a general mixture of species such as *Artocarpus integrifolia* (Jak), *Sterculia fœtida*, *Michelia champaca*, (Sapu) *Melia dubia*, and others.

Leaves From Dadap Trees.

The species of Erythrina, commonly known as Dadaps, are, however, of the most importance and these together with *Albizzia moluccana* can now be considered.

In Ceylon, *Erythrina lithosperma* is being favoured in preference to *E. umbrosa* on account of its more rapid growth, more luxuriant foliage, absence of thorns, and the way in which it stands regular lopping once or twice each year. Large numbers of seeds have been distributed to cacao-growing countries; in favourable climates the tree appears to be giving good results. The following analyses show the composition of the leaves of *Erythrina lithosperma* in Ceylon * :—

	Fresh leaves. per cent.
Moisture	60 to 80
Lime	0·197
Potash	0·148
Phosphoric acid	0·08
Nitrogen	0·3 to 0·8

If this species is frequently lopped, the old trees rung and the vacancies regularly supplied with long healthy cuttings, the weight of leaves obtainable far exceeds that from any other species with which experiments have been made at Peradeniya. On an acre of land planted 8 x 4 feet, the weight of fresh *leaves alone* in one year amounted to no less than 11,000 lb., and it can be confidently stated that on cacao estates with every cacao plant interplanted with cuttings of this species about three to four tons of fresh leaves and twigs per acre, per year, can be obtained by the system of cultivation just outlined. The manurial constituents in such material can be easily calculated. The points to lay stress upon in connection with the use of dadaps as green manures in cacao are: (*a*) that cuttings of dimensions quoted should be used; (*b*) the cuttings should be planted in holes 1 foot deep; (*c*) planting should be done only in the rainy seasons; (*d*) when used in connection with cacao they should be regularly lopped, rung, and re-supplied. The object should be to avoid permanent occupation of the land by anything except the cacao under cultivation. The weight of fresh leaves obtainable, per acre, per year, may be judged from the following results when planted 8 x 8 feet among newly-planted tea.

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* M. Kelway Bamber, Committee of Agricultural Experiments, Peradeniya.

Weight of Fresh Dadap Leaves.

Cuttings Planted July, 1904, 8 by 8 Feet.

Month when Pruned		Weight of Leaves in lb.
November	1904	791
December	,,	967½
March	1905	1,935
April	,,	1,444½
May	,,	2,255
June	,,	2,240
July	,,	2,180
August	,,	3,058
September	,,	1,569¾
November	,,	2,104¼
December	,,	1,653½
May	1906	9,205
August	,,	10,126

Even when the trees are allowed to continue growing uninterruptedly for three years, the quantity of leaf which naturally falls to the ground is enormous; decomposition is always taking place, and the leaves of dadaps being comparatively soft are speedily decomposed. The observations recorded elsewhere show, however, that the balance left on the soil from the leaf-fall for nine months only was 2904 lb., the greater part of which rapidly disappeared after a few weeks of rain.

Nitrogen in Flowers of Erythrina.

Carmody * has made the following interesting calculations regarding the nitrogen content of the flowers of the Immortel, *Erythrina umbrosa*, used as shade for cacao in the West Indies:—

50 immortels = 800 lb. dry flowers, at 3 % of nitrogen = 24 lb. per acre.

250 cacao trees = 500 lb. cured cacao, at 2½ % of nitrogen = 12½ lb. per acre.

This shows an excess of about 12 lb. of nitrogen per acre, and Carmody concludes that "apart from the question of the retention of the Immortel as a shade tree, the results of this investigation suggest that flowering trees may be utilised to keep the nitrogen of the soil in circulation and to conserve it by bringing it from lower depths in soluble form and periodically spreading it in a less soluble but easily decomposible form on the surface of the soil". In addition to the nitrogen in the flowers brought up from various depths of soil, that absorbed from the air by means of the bacteria in the root nodules should be taken into account.

* Trinidad Agr. Soc., June, 1902.

Chemical Composition of Different Legumes.

The following analyses * show the percentage of nitrogen and other ingredients in various legumes grown in cacao-growing districts :—

Bonavist Seeds, Sample	1	2·77	per cent.	nitrogen.
,, ,, ,,	2.	3·22	,,	,,
Mungo Pea ...	...	3·06	,,	,,
Cow Vetch (Mucuna)	...	5·56	,,	,,
Lima Bean	...	3·22	,,	,,
Sugar Bean	...	3·38	,,	,,
Average	...	3·36		

The Bean of the Saman, *Pithecolobium saman*, dried at 130° F. contains :—

	Per cent.
Nitrogen	2·31
Glucose	21·45
Gums, Pectins, etc.	17·58
Albumenoids	14·44
Oils, Fats	1·51
Starch, etc.	27·07
Indigestible fibre	5·85
Mineral matters	2.84
Water	9·26
	100·00

Albizzia moluccana.

This tree differs from the species of Erythrina in its more rapid growth and preponderance of woody tissue. It is regarded as one of the quickest-growing trees in the tropics, and though it sheds a portion of its leaves during the year it is never even partially leafless, and can be considered a typical evergreen shade tree. The trees can be regularly lopped after they are 1½ to 2 years old; the foliage, though less abundant than that from Erythrina species, is rich in essential ingredients. The following tables show the weight of foliage obtained from trees on a one-acre plot, planted 20 x 20 feet apart, and the average composition of some samples of leaves.

Leaves of Albizzia moluccana.†

	Fresh, per cent.
Lime	0·441
Potash	0·406
Phosphoric acid..	0·178
Nitrogen	0·395

* Harrison, Bul. of Misc. Information, Trinidad, July, 1901.

† M. Kelway Bamber.

Weight of Foliage from Prunings.

Trees Planted July 1904, 20 by 20 Feet.

Month when lopped	Weight of fresh foliage in lb.
March, 1905	232
June ,,	529
July ,,	339
September ,,	1,203
January 1906	942
May ,,	3,179

Trees of *Pithecolobium saman*, *Hevea brasiliensis*, and *Castilloa elastica*, common on many cacao estates, are typical deciduous trees, and the following table will give some idea of the plant food present in the foliage * of two of these species.

Composition of Leaves.

	Hevea brasiliensis. Dried at 100° C.	Castilloa elastica. Dried at 100° C.
Ash	4·69 per cent.	13·08 per cent.
Lime	0·51 ,,	2·05 ,,
Potash	1·72 ,,	1·86 ,,
Phosphoric acid	0·60 ,,	0·47 ,,
Nitrogen	3·44 ,,	3·20 ,,

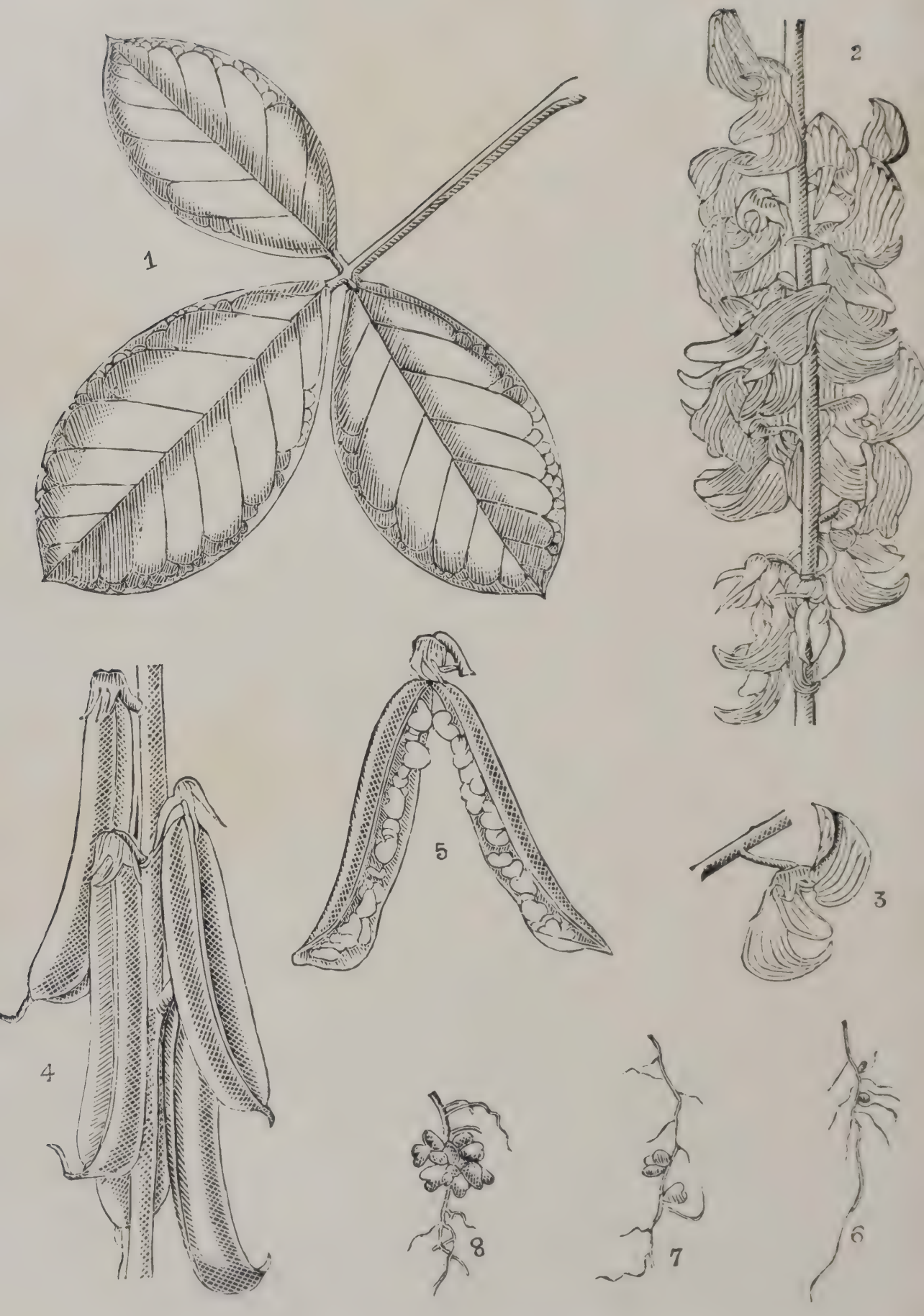
It is obvious from the foregoing statements that in the cultivation of cacao we are dealing with a type of mixed artificial forest, and in the accumulated foliage from the various trees are large quantities of valuable plant food. The weight of essential ingredients taken from the soil in the crop of cacao beans is small compared with that contained in the annual accumulation of foliage from the plants occupying cacao land, and if the latter—though auxiliary—are properly cultivated the plea for very large additions of artificial manures seems to have but little to commend it. The frequent turning in and subsequent decomposition of large quantities of organic matter are followed by a conversion of soil particles from the insoluble to the soluble form, much plant food is liberated, and the physical conditions of the soil greatly improved.

Herbaceous Plants in Ceylon.

In addition to the tree forms already described there are on many estates large quantities of weeds, and in some cases specially selected species of green manure plants are grown on cacao land, to be used as manure.

Herbaceous plants can be best grown on cacao clearings from the first to the fourth year on account of the abundance of light which they are able to obtain and the relative freedom of the soil particles. The plants which can be used are *Crotalaria striata*, D C., *C. laburnifolia*, L., *C. incana*, L., *Cajanus indicus*, Spreng, and species of *Indigofera*. Phascolus, and *Cassia*. These plants are shrubby in habit, grow to a

* M. Kelway Bamber, Committee of Agr. Expts., Peradeniya, 1905.



Leaves (1), Flowers (2 & 3), Fruits (4 & 5), & Nodules (6 to 8), of CROTALARIA STRIATA.

height of one to five feet and will stand pruning at intervals of four to six months. Trailing or creeping plants such as the ground-nut and species of *Vigna*, and *Phaseolus* can be successfully grown and also the Sensitive Mimosa plant. All these give a good cover to the soil and help to keep the weeds in check and produce large quantities of organic matter rich in plant food. Space forbids a full account of this subject, but the following facts are of interest as showing the weight of green material obtainable and the composition of several herbaceous species:—

Name of plant.	Weight of organic matter per acre.	Time between sowing and uprooting.
Crotalaria striata ...	20,244 lb. ...	10 months
Vigna	12,092 ,, ...	4 ,,
Pondicherry groundnuts.	4,692 ,, ...	5 ,,

Composition of Various Green Plants, in the Fresh State

Name of plant.	Nitrogen per cent.	Potash per cent.	Phosphoric acid per cent.	Lime per cent.
Crotalaria striata.. ...	0·7 to 1·0	0·47	0·154	0·210
Vigna...	0·6	0·738	0·177	0·727
Pondicherry groundnuts ...	0·914	0·493	0·155	0·242

It is interesting to work out what the equivalent of 15,000 lb. of green manure of *Crotalaria striata* is, from a purely theoretical standpoint.

According to the above analyses it is approximately equal to manure of the following composition.

Castor cake	500 lb.
Blood meal	500 ,,
Nitrate of soda	140 ,,
Basic slag	115 ,,
Potassium sulphate	140 ,,

If the whole of the material is to be used it should be buried with lime or basic slag around the trees as previously explained. During its decomposition it liberates large quantities of plant food which might otherwise remain in a latent stage for many years.

For the successful cultivation of herbaceous green manures about 10 to 20 lb. of seed, per acre, should be broadcasted on clean land in wet weather, and the land lightly forked. In Fiji as much as 50 lb. of Vigna seed is used per acre.

Green Manuring in Cacao.

The utilisation of the leaves of plants on cacao estates, in the fresh or partly decomposed state, is commonly referred to

* See Hevea brasiliensis, 1906.

as the practice of green or organic manuring, and the subject may be discussed here. The quantity of fresh organic matter obtainable from the leaves of the cacao trees, weeds, cultivated herbaceous and tree forms, and their general composition, have been previously touched upon, and it now only remains to make a few remarks on the principles involved.

Advantages of Green Manuring.

No matter what plants are used, whether they are leguminous or otherwise, there are certain advantages attending their occupation on any Ceylon soil. It is well-known that large quantities of soluble food are lost in percolating water and drainage, the greater part of which can be absorbed and retained by a growing crop. This applies to land partially occupied by growing cacao trees, but more particularly to newly-opened clearings. It is impossible to exaggerate the loss that must take place from the soil when allowed to remain exposed to the sun and rain or in young clearings of cacao which are continually scraped by weeding contractors. In the second place, the green crop provides large quantities of organic matter—a substance which is often deficient in cacao soils—and which when introduced leads to the liberation of food supplies and improvement in the physical properties of soil. Again, it reduces the amount of wash in a varying degree, the maximum reduction in the shortest time being obtained by the use of herbaceous forms similar to *Crotalaria* species. Finally, it protects the soil from the hot rays of the sun and regulates the moisture conditions of the soil, so that bacterial activity, responsible for the liberation of much plant food, is more uniform throughout the year. These are advantages which will accrue from the cultivation of *Tithonia*, *Adhatoda*, mustard, or leguminous plants. If, however, plants belonging to the natural order *Leguminosæ* are selected, large quantities of atmospheric nitrogen may become fixed by the plant and ultimately turned into the soil. A green crop of cow peas, 6 tons in weight, contains as much nitrogen as can be obtained from 800 lb. of 6 per cent. castor cake, or from 320 lb. of nitrate of soda. Nitrogen is one of the most important of the essential ingredients; it is often present in very small proportions in cacao soils, and is the most costly ingredient of manures commonly used. The main objects of green manuring in cacao are to accumulate organic matter and nitrogen in the soil to protect the soil, and to check the growth of weeds.

Arborescent Plants for Manuring Purposes.

The fact that most of the cacao in Ceylon is grown under partial shade makes it almost impossible to obtain good results with herbaceous green manures, owing to an insufficiency of light. In cacao, which is only lightly shaded, species of *Indigofera*, *Vigna*, and *Crotalaria* are useful. For most cacao estates, however, green manuring can best be accomplished by using the plants grown to protect the cacao against wind and intense light. The tree forms

considered elsewhere, *Erythrina lithosperma* and *Albizzia moluccana* can be and are used in this way, as they can be regularly lopped, rung, and resupplied at less frequent intervals than with many other products. If they are allowed to grow without being lopped, they will become a danger to the cacao and aid in the spread of disease. It is obvious that the use of *Dadaps* and *Albizzia* as sources of green manure in cacao does not necessitate entire removal of shade. It only means that the shade is maintained as desired and yet nothing allowed to permanently occupy the land except cacao. Furthermore, the frequent lopping of the trees used as shade will prevent the cacao trees from becoming too spindly. The advantage of having low well-branched cacao trees is only too well-known to planters who have to harvest the crop as cheaply as possible and to keep all parts of the cacao tree under observation in connection with the diseases of this product.

Influence of Leguminous Trees on Manuring.

Most authorities agree that where leguminous shade trees are used, manuring should be modified by a reduction in nitrogenous manures; the potash, phosphoric acid, and lime are necessary to enable the cacao and shade trees to put on the best growth.

The following manures have been recommended for the West Indies, according to whether shade trees are or are not used:—

	Erythrina used for shade.	Not shaded.
Nitrate of Soda	1 cwt. ...	2 cwt.
Superphosphate of lime, 36 per cent. soluble	¾ ,, ...	½ ,,
Potash sulphate	1 ,, ...	½ ,,

Natural Animal Manures.

On many cacao estates, cattle and pigs are often kept. The manure from these should be kept under cover in well-drained and ventilated sheds, provided with convenient arrangements for retaining the liquid portions which run off from the fresh and decomposing heaps. The following analysis was made by Mr. Bamber in 1903 of a sample of cattle and pig manure used for manuring cacao plots at Peradeniya:—

Analysis of Cattle and Pig Manure.

Moisture lost at 212° F. ... ... 57·90 per cent.

Composition of the Sample Dried at 212° F.

Organic Matter	34·20 ,,
Phosphoric acid	1·84 ,,
Potash	1·60 ,,
Iron, Lime, etc.	10·65 ,,
Insoluble matter	51·71 ,,
	100·00
Nitrogen	1·39 per cent.
Equal to Ammonia	1·69 ,,

Pen Manures.

Some West Indian authorities recommend the use of stable and pen manures in preference to all other fertilisers for exhausted cacao soils; Boname gives the following analysis of well-preserved pen manures:—

	In their usual damp state.
Mineral Substances ...	4·42
Giving Phosphoric acid ...	1·90
Potash ...	2·30
Lime ...	3·90
Soda ...	0·60
Organic substances ...	14·22
Giving Nitrogen ...	4·00

When the same material has been kept under cover and dried for months or years the percentage of water in the residue has decreased and the mineral and other ingredients increased in proportion. Some old, dried, and concentrated pen manures are reputed to possess 12 per cent. of potash and about 20 per cent. of nitrogen.

Artificial Manures.

These manures differ from those of the natural series in being more concentrated and more readily available; they may comprise mineral manures rich in potash, phosphoric acid, or lime, or organic manures when the predominant constituent is usually nitrogen.

Composition of Artificial Manures.

The following table shows the ingredients of common artificial manures obtainable from local firms; the compositions here quoted are those guaranteed by various firms in Colombo.

Manure.	Potash.	Phosphoric acid.	Nitrogen.
	per cent.	per cent.	Per cent.
Blood meal ...	—	—	10 to 14
Groundnut cake ...	1 to 2	1 to 2	7½ to 9
Castor cake ...	1 to 2	1 to 2	6 to 7
Rape cake ...	1 to 2	2 to 3	5 to 6
Nitrate of soda ...	—	—	15 to 16
Sulphate of Ammonia ...	—	—	20½ to 21½
Chloride of potash ...	57 to 59	—	—
Sulphate of potash ...	49 to 52	—	—
Precipitated phosphate of Lime ...	—	35 to 4	—
Concentrated superphosphate ...	—	44 to 46	—
Basic slag ...	—	19¾ to 21	—
Fish ...	—	4 to 6	5½ to 6½
Bone dust ...	—	23 to 24	3½ to 4
Nitrate of potash ...	37 to 40	—	11 to 13
Kainite ...	13 to 15	—	—

Manuring in the West Indies.

In Grenada, where manuring is largely adopted, the trees give a fair crop when only four to five years old, but it is asserted that in Trinidad, where one manures little, good crops are not obtainable until about the tenth year.

According to Guerin* a proper system of manuring enables the trees to overcome the attacks of borers, the insects finding themselves choked by the exuberant vegetation. Regular manuring ensures regularity in crop and prolongs the life of the tree. If one ceases to manure in Grenada, Preuss asserts that the vitality of the plantation will soon be lowered. Farmyard manure, oil cakes, and composts of leaves form excellent manure, but should be supplemented with mineral manures rich in potash. Wood ashes are recommended by Boname, Lecomte, and Chalot on account of their richness in potash constituents. The best time to apply the manures is said to be at the end of the rainy season. The phosphoric and potassic manures are in part absorbed by the soil and become more or less fixed; the nitrates are more liable to be lost in drainage. In all cases, however, the manures should be applied in association with the periods of plant activity. The results obtained in many parts of the West Indies are given in the chapter dealing with yields.

Watts has made numerous experiments regarding the manurial value of weeds found growing on a cacao estate at Dominica and has shown that the weeds on one acre† contained the equivalent of 3 cwt. of sulphate of ammonia, 1½ cwt. sulphate of potash, and 1 cwt. of basic slag. From the results of experiments in St. Lucia,‡ the authorities appear to favour the growing of weeds and leguminous plants to turn into the soil as green manure, rather than the growing of weeds to be periodically cut and allowed to rot on the surface; very good results were obtained by mulching with grass and leaves and the sweepings of the lawns. The actual results obtained by these and other methods of manuring are given in a separate chapter on yields.

Methods in St. Lucia.

In St. Lucia after five years' experience§, the Botanic Station authority states that good results have been obtained from the following method:—"Forking throughout the plantation in January, then applying broadcast eight cwt. of the basic slag between January and April; this is followed by draining where necessary, and then thorough pruning. We find pruning to be of very great importance

* Culture du Cacaoyer, by Dr. P. Guerin, Journal D'Agriculture Tropicale, 1903.

† Bulletin of the Department of Agriculture, Jamaica, Vol. III., December 1905.

‡ Reports on Experiment Stations, St. Lucia, 1904-05.

§ Annual Reports, St. Lucia.

as it admits sunlight. After this thorough cleanliness throughout the year. Three to four weedings are usually sufficient, but sometimes as many as six have been found necessary. In August or September we apply sulphate of ammonia to each tree. I observe from the results of the experiments in Grenada, that the best yields have been obtained from an application of sulphate of potash. In 1902 we applied nothing but potash to a 6-or-7-acre plot, and the results were negative in every case. I may mention, however, that in combination with basic slag, the experiment has proved very valuable, but the best results were obtained from a combination of slag and nitrogen. We have also tried superphosphate but have not found it advantageous. We have obtained good results from ground bone, but that is rather expensive. Pen manuring is undoubtedly the best system, but the difficulties of transportation prevent its general adoption. Chemical manures yielded as good results and at less cost. The only fear in the application of chemical manures is that too much nitrogen may be applied to certain soils, but in light soils there is nothing to fear. Many planters seemed to fear forking, on the ground that it injured the trees, but I have never seen any bad results from careful forking. Owing to the results obtained on the experiment plots, planters in St. Lucia are now importing basic slag and sulphate of ammonia; pruning and forking have now become a recognised part of cacao cultivation". Many of these results agree with those obtained in Ceylon, but others appear to show considerable differences.

Manuring in Dominica.

One West Indian authority* has strongly urged the substitution of excessive tillage and clean-weeding in orchards, by a system of green dressing, or the use of weeds and shrubs for manures, which he asserts has all along existed in Dominica. "The weeds are allowed to grow, and at intervals these are cut down without materially disturbing the surface soil; the cuttings are either used as a mulch or they are treated as a green dressing and bedded in. The crop that has been found most useful so far appears to have been woolly pyrol especially where it is shown hat the amount returned is very considerable. "Around each tree a space of about 10 feet is kept perfectly free from weeds; the remainder of the land remains largely untilled: the weeds are cut down and are either left as a mulch to find their way into the soil, or are at once dug in". Hudson, on the other hand, recommends that the cacao land should be kept clear of weeds.

Farmyard manure has also been strongly recommended in Dominica not only for supplying all the ingredients required but for the mechanical improvement of the soil which its application effects. Estates in the interior or in bad situations are, however, compelled to use artificial manures, and large quantities of basic

* Dr. Francis Watts, Bulletin, Jamaica, Sept. 1905.

slag and various nitrogenous manures have been used. In addition to these, there are always plenty of dead leaves, lopped shrubs and grasses available in the forests, which can be used as a mulch for the trees and subsequently forked into the soil.

Cacao Manuring in Trinidad.

At the Agricultural Conference held in Trinidad in 1905, Gannes stated that the cacao planters in that island were realising the necessity of higher cultivation, and that where artificial manures had been tried the results were encouraging, Basic slag appears to have been generally applied; good results were also obtained by the use of pen manure prepared with gypsum, and with sheep manure.

Manuring in Samoa.

Up to the present the results obtained and the methods adopted in Samoa are not widely known, but it is surmised that experiments are being carried out by the German Trading and Planting Company, according to Wohltmann's* instructions. It has been shown that the cacao soils in Samoa are moderately rich in phosphoric acid and nitrogen, and that lime can be obtained from the coral sands, and potash from the wood ashes, both locally available. The recommendations which have been published advise that manuring should be done to supply food, to improve the physical properties of the soil and increase its power of retaining water in the dry weather. The manures are applied in the dry weather when weeding is being done, the surface of the soil being hoed to a distance of about three feet from the stem of the cacao tree; this area should, it is advised, be covered with a layer of dead weeds to protect the soil from drying—a practice deprecated by many West Indian cultivators. The hoeing is done carefully, only the superficial soil being disturbed with minimum damage to the roots.

Mineral Manurial Constituents: Potash.

The manuring of cacao and the composition of cacao soils in various parts of the tropics have been dealt with by Couturier. The importance of potash for the production of cacao is strongly emphasised from the results of analyses as well as those of manurial experiments on many plantations. Boname has shown that each ton of marketable cacao corresponds to 8.130 kilograms of fruits; each ton of cacao takes from the soil 112 kg. of mineral matter of which 57 kg. are potash, 9 kg. phosphoric acid, and 20 kg. nitrogen.

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* Bulletin, Imperial Institute, London, March, 1904.

Wohltmann, in his account of Samoan soils, enters into a calculation of the amount of potash removed by a crop of cacao, and the following is the result arrived at:—

100 kg. of cacao beans = Potash in kernels		0·883 kg.
= Potash in integuments		0·261 ,,
	Total	1·144 ,,

If there are 500 trees to each hectare and each tree yields 2 kg. of cacao per year, we have 1000 kg. of beans. This quantity of cacao therefore takes 11·44 kg. of potash, per hectare, per year.

Potash Manures.

The potash can be applied either as the sulphate containing 50 to 54 per cent. of pure potash, as the chloride or muriate possessing 50 to 52 per cent. of potash, as nitrate of potash, or as kainit which contains 12 to 16 per cent. of pure potash. Potassium chloride is very soluble, 100 parts of water dissolving 32 parts of the salt, and its application to soils in very wet districts may be accompanied by considerable loss in the drainage water; in very wet districts preference is usually given to the sulphate of potash, which, though slightly dearer, is less soluble than the chloride. Other manures such as Guano, castor cake, groundnut cake, etc., contain small quantities of potash.

Phosphoric Acid.

The various analyses of parts of the cacao tree do not always show agreement in the relative proportions of phosphoric acid to other ingredients. Boname shows that the unavoidable loss of phosphoric acid in Venezuela is sometimes greater than that of potash; many analyses support and others reverse this conclusion. The complete analyses of all parts of cacao trees show that phosphoric acid is of considerably less importance than the potash, but it is clear from Cockran's analyses that the proportion of phosphoric acid is at the minimum in roots and leaves and at the maximum in the seeds. A reference to the chapter dealing with the chemistry of the cacao tree will show the varying importance of phosphoric acid as indicated by analyses of separate parts of the cacao trees.

Phosphoric acid may be applied in very stable forms such as fish manure, fish guano, bone meal, crushed bones, and steamed bone dust, or in more readily available doses of basic slag, ordinary superphospate of lime, concentrated superphosphate, precipitated phosphate of lime, flour phosphate, etc. In parts of the West Indies and Ceylon, basic slag or Thomas's Phosphate is a very popular form of phosphoric acid, and can be used either in association

with organic matter or mineral manures; the free lime it contains aids materially in decomposing vegetable matters.

Potash and Phosphoric Acid.

The results of analyses of parts of the cacao plant, and especially the seeds, show that the proportion of potash is usually, but not always, much higher than that of phosphoric acid, and one may naturally conclude that potassic manures may be more urgently required than those containing phosphoric acid. It is obvious, however, that on certain soils the application of phosphates in the form of basic slag has been accompanied by very good results; sometimes nitrogenous manures have been applied, and at other times potassic salts, with the basic slag. Harrison and others in the West Indies have found beneficial results to accrue from the application of basic slag and nitrate of soda or sulphate of ammonia—a mixture which does not possess any potash. It may be that the soils which were thus experimented with contained sufficient quantities of potash; in the soils described by Couturier, the best yields were given by those possessing large quantities of available potash. These instances show how necessary it is to determine the composition of the soil before applying artificial manures of any kind, and the uselessness of giving types of mixtures to be used by cacao planters whose soils and climates differ greatly. Harrison* states that his experience in the West Indies has led him to believe in the great importance of potash in an available state present in the soil, and to the lesser importance of phosphoric acid and nitrogen.

Lime and Magnesia.

The importance of lime is manifest from a consideration of the analyses of cacao seeds; and the effect on the soil as a liberator of plant food, a sweetener of sour soils, and improver in physical properties, are only too well known. From the results of experience in Ceylon it appears necessary to point out that the repeated application of lime without that of other manures is not advisable; at Peradeniya an application of lime has either preceded or followed the forking in of large quantities of organic matter.

Magnesia shows up prominently in many analyses of cacao as well as in other fruit trees, but it is usually assumed that the soils can generally supply all the magnesia required by the cacao crop. The ratio of lime to magnesia is supposed by many to be of considerable importance, and an application of lime or ground limestone containing a fair amount of magnesia has been recommended by Cockran. It will be remembered that the analyses made by Cockran showed that the seeds of cacao alone made a greater demand on the magnesia than the lime; lime is given as a dominant constituent

* Tropical Agriculturist, Colombo, November, 1899.

in roots, stems, branches, and leaves, and magnesia as distributed in considerable proportion through all parts with concentration in the seeds.

Nitrogen.

Nitrogen is obviously essential for the production of healthy cacao trees and large crops, but its importance is modified by the conditions of cultivation prevailing. It is acknowledged that cacao plants when grown alone require larger quantities of nitrogenous manures than under any other conditions; when shade trees are used the amount of nitrogen required is reduced, and if the additional trees belong to the leguminous group the cacao plants frequently give healthy and large crops with the addition of the minimum quantity of nitrogenous manures. Heavy applications of very soluble nitrogenous manure often lead to a too abundant leaf production and shedding of cacao flowers. Harrison recommends that nitrogenous manures should be supplied as a rule in light dressings only, of not more than one cwt. nitrate of soda per acre, to be applied when the main crops have just been picked. Harrison gives preference to nitrate of soda against sulphate of ammonia.

The Value of Natural and Artificial Manures.

Having dealt with the various natural and artificial manures and the results obtained by their use in connection with cacao in different parts of the world, it is now necessary to consider their comparative values. It must be admitted that the results obtained in parts of the West Indies and Ceylon are frequently opposed to one another, if the criterion is the increased yield per unit of expenditure. In a general way it may be stated that the use of pen and similar manures in the West Indies have given the best results, but that the expense incurred is often such as to render this method prohibitive; similarly, in parts of Ceylon some of the finest cacao areas, in appearance and yielding capacity, are those which have never received any manure except lime, leaves, and the material from the cattle sheds. The results obtained by forking in the leaves of green manures, of mulching weeds, leaves etc., have given moderately good results, though in several instances the practice seems to have been accompanied by but little improvement.

The cultivation of herbaceous plants, under the cacao, for green manuring, often leads to an interference in the root growth of the cacao trees; the obtaining of a sufficiently large amount of foliage from trees frequently occasions the growing of dense forests above the cacao, often to the disadvantage of the latter. The methods adopted and results obtained in Dominica and St. Lucia by Watts and Hudson respectively, as well as those outlined elsewhere, should be fully considered; the general opinion appears to be that the

cultivation of plants to supply large quantities of organic matter will, perhaps, be accompanied by better results when the methods are understood.

The effect of the various manures used in St. Lucia, Grenada, and Trinidad have been ably described by Thompson, before the Agricultural Society, Trinidad. At St. Lucia the control plot which did not receive any manure gave 5 lb. dry cacao per tree; that which was treated with vegetable manure (15 tons) gave $6\frac{1}{4}$ lb. dry cacao per tree, and the plot which received commercial manure (4 cwt.) gave 7 lb. dry cacao per tree. At Grenada one plot received 15 tons of pen manure, or three baskets per tree, and the yield was increased over a period of four years from $5\frac{5}{8}$ to $6\frac{1}{3}$ bags per acre, and the average of three plots treated with commercial manures showed an increase from $5\frac{1}{8}$ to $8\frac{2}{3}$ per acre in four years. Similarly with numerous other plots treated with natural and artificial manures.

Manures Which Have Given Good Results.

Country.		Nature of mixture.
Trinidad.	...	Basic slag, 4 cwt. per acre.
	...	Sulphate of potash, 1 cwt. per acre.
St. Lucia.	...	1 Basic slag, 8 cwt. per acre.
	...	Sulphate of ammonia, 1 cwt. per acre.
St. Lucia.	...	2 Basic slag, 4 cwt. per acre.
	...	Stable manure, 3 tons per acre.
	...	Sulphate of ammonia, 1 cwt. per acre.
Grenada.	...	1 Basic slag, 8 cwt. per acre.
	...	Sulphate of ammonia, $1\frac{1}{2}$ cwt. per acre.
Do.	...	2 Basic slag, 8 cwt. per acre.
	...	Sulphate of potash, 1 cwt. per acre.
Dominica.	...	1 Mulching with grass and leaves.
Do.	...	2 Basic slag, 4 cwt. per acre.
	...	Sulphate of potash, $1\frac{1}{2}$ cwt. per acre.
	...	Dried blood, 4 cwt. per acre.
Ceylon.	...	1 Lime and organic matter; the latter either as leaves or cattle manure.
Do.	...	2 Basic slag 5 cwt. Ammonium sulphate 200 lb.
Do.	...	3 Manures rich in readily soluble nitrogen and potash.

Cacao Manures.

Cockran * gives the following manures as examples of mixtures suitable for cacao under various conditions :—

I.

	Per acre.
Superphosphate of lime 36 per cent. soluble ...	182 lb.
Sulphate of potash 50 per cent. potash ...	120 ,,
Nitrate of soda	237 ,,
or (Sulphate of ammonia 186)	

II.

	Per acre.
Bone meal	300 lb.
Sulphate of potash	120 ,,
Castor cake	400 ,,

III.

	Per acre.
Thomas's Phosphate powder	360 lb.
Sulphate of potash	120 ,,
Castor cake	570 ,,

IV

	Per acre.
Thomas's Phosphate powder	360 lb.
Sulphate of potash	120 ,,
Blood meal	300 ,,

V.

	Per acre.
Fish manure	500 lb.
Bone meal	200 ,,
Sulphate of potash	120 ,,

IV.

	Per acre.
Nitrate of soda	119 lb.
or (Sulphate of ammonia 93)	
Blood meal	100 ,,
or (Castor cake 200)	
Bone meal	150 ,,
Sulphate of potash	120 ,,

In all cases Cockran allows that a reduction in the quantity of nitrogenous manures may be made when leguminous trees are grown for shade purposes. These mixtures, for reasons already given, cannot be applied to soils of unknown composition ; they are quoted to show the general nature of manurial mixtures which have been recommended.

* M. Cockran, Report of analysis of the Cocoa tree. Planters' Association of Ceylon, 1898, p. 11.

CHAPTER XIV.

YIELDS OF CACAO.

THE yields of cacao obtainable depend on many factors; in this chapter we have to deal with the yields obtained with and without the use of manures. A considerable amount of information is available regarding the average yields in various parts of Ceylon, Trinidad, Grenada, St. Lucia, Dominica, Central and South America, and only a synoptical account of the results which have been published can be given.

The average cacao estate possesses from 200 to 300 cacao trees per acre, and an annual yield of from less than one to over five pounds of dry cacao per tree has been recorded. The cacao trees may begin to bear flowers and fruits in their third and fourth years, but it is usually considered advisable to prune all the flowers which occur in the first blossom; this prevents the concentration of valuable mineral and proteid constituents in the seeds, and allows these materials to be used in the development of a better vegetative system from which heavier crops may be subsequently expected. Many planters consider that the fruits borne on the main trunk are better in quality and weight than those on the branches, and on estates where the development of a single or main stem with the minimum number of branches and suckers is aimed at, these differences require consideration.

Yields and Varieties.

The variation in yield from cacao plants of different varieties when grown on adjacent plots of land is often greater than that observable on control and manured plots of the same variety; this difference in the natural yielding capacity of varieties, which on ordinary estates are so hopelessly and irregularly mixed, makes manurial experiments often of very little value. The effect of a known manure on trees of the Amelonado and Nicaraguan-Criollo varieties respectively will probably be vastly different; under normal conditions the finer quality cacaos may be expected to give poorer yields than the inferior Calabacillo or Amelonado types.

Yields of Cacao in Ceylon.

It has been previously shown that the yield of cacao varies according to age, variety, and methods of cultivation adopted, but on most Ceylon estates an average annual yield of 250 to 350 pounds of cured cacao per acre is considered moderately good, one of 500 to 900 lb. and over very good, and below 150 lb inferior. The following table, based on figures of export furnished by the Principal Collector of Customs, Colombo, and acreages as

given in Ferguson's Directory, shows the average export from Ceylon, per acre, and the area of cacao under cultivation, during certain years:—

Year.	Acreage in Cacao.	Export of dry Cacao.	Yield of dry Cacao per acre.
		cwts.	cwts.
1893	16,286	29,775	1·8
1894	17,000	22,791	1·3
1895	18,278	27,522	1·5
1896	18,330	33,890	1·8
1897	20,000	35,121	1·7
1898	21,260	38,098	1·7
1899	22,000	42,527	1·9
1900	23,696	33,696	1·4
1901	24,136	47,471	1·9
1902	24,867	61,476	2·4
1903	24,900	59,098	2·3
1904	25,000	67,355	2·6
1905	25,146	69,431	2·7
1906	25,943	55,621	2·1

Yields on Estates in Ceylon.

Individual estates show great variation, from year to year but the figures given below will indicate yields commonly obtained

District.	Year.	Yield of dry cacao, per acre, in pounds.
Peradeniya (a)	1903	132
,, ,, ...	1904	232
,, ,, ...	1905	403
Peradeniya (b)	1902	196
,, ,, ...	1905	336
Peradeniya (c)	1905	504
Matale (a)	1902	254
,, ,, ...	1903	122
,, ,, ...	1904	114
,, ,, ...	1905	126
Dumbara (a)	1901	132
,, ,, ...	1902	142
,, ,, ...	1903	224
,, ,, ...	1904	168
,, ,, ...	1905	260
Dumbara (b)	1900	425
,, ,, ...	1901	236
,, ,, ...	1902	481
,, ,, ...	1903	673
,, ,, ...	1904	560
,, ,, ...	1905	588
Dumbara (c)	1905	1,026
Badulla (a)	1904	140
,, ,, ...	1905	180
Matale (b)	1902	150
" "	1903	160
" "	1904	140
" "	1905	190

One large acreage of about 7,000 acres, in Ceylon, has given a little over 15,000 cwt. of dried cacao, or on an average a little over 2 cwt. per acre.

Yield per Tree at Peradeniya.

At the Experiment Station, Peradeniya, where the trees vary in age from four to twenty years, the following yields have been obtained:—

Year.	Number of trees.	Total yield of cured cacao.	Yield in lb. per tree.
		cwt.	
1903 ...	29,225	136½	0·52
1904 ...	28,572	240¾	0·94
1905 ...	33,199	361⅔	1·21

These figures show the average yield per tree, per year, over a period of three years, on an estate of 100 to 116 acres. In 1903 the cacao was very badly diseased, and the increase in yield during 1904 and 1905 was mainly due to carrying out proper sanitary measures and judicious manuring. It should be mentioned that a very large number of the trees in 1905 were bearing fruits for the first time, and that owing to their being so closely planted the total yield often exceeded 3 cwt. per acre.

Manurial Experiments and Yields at Peradeniya.

A large number of manurial experiments have been carried out at the Experiment Station, Peradeniya, to determine the effect of known quantities of nitrogen, potash, and phosphoric acid, applied in various forms, on the cacao plants and the yield of cacao seeds. In the tabulated results the application of manure has been made each year, except where otherwise stated, from 1903 to 1906, both years inclusive, but for details reference should be made to the writer's annual reports during the years mentioned.

Effects of Manures.

It is very difficult to define the effect of a given manure in terms of increased cacao crop alone, in plots unequal in parentage and occupied with trees other than cacao. This is obvious from the fact that, in the first year, the control plot in the Peradeniya experiments, which was not treated in any way, gave a better crop than the majority of the areas experimented with. Furthermore, one special plot which from its appearance suggested a healthy condition and promised a good crop, was eliminated from the experimental area, and, though never treated with manure, gave a crop of 10,334 fruits, equal to about 5 cwt. per acre, a yield far in excess of that from several manured plots. Other examples might be quoted to prove the same necessity for caution.

The experiments were carried out during 1903 to 1906 to determine the effect of excess and normal quantities of nitrogen, potash, and phosphoric acid, and the relative value of the more general manures and modes of cultivation.

Results in 1903.

There were no very striking differences to be noted in the first year in connection with the plots treated with excess of readily

soluble manures beyond the active leaf production which occurred on plots treated with potash and nitrogen. The weeds on these plots developed at a rapid rate, and were subsequently turned into the soil.

One tree on the plot purposely treated with excess of concentrated superphosphate dropped nearly all its leaves two months after the manure was applied; there was very little disease on the tree, and the curious behaviour could not be accounted for except by temporary inactivity of the root system. Before the tree dropped all its leaves the little canker present was excised. In a few weeks' time new leaves appeared, and the tree is now quite healthy. This tree was supplied with a very heavy dose of concentrated superphosphate, and a large portion of this soluble manure appears to have been readily absorbed, and to have more than satisfied the requirements of the plant. The experiments with general manures were commenced on plots of established trees, the plots chosen being fairly representative of those on cacao estates. In comparing the total yields, allowance must be made for the fact that the age of the trees on the different plots varied, the varieties were numerous and in varying proportions, and other trees existed in different proportions on the selected areas. These reasons are sufficient to prevent one becoming too positive as to the relative value of the different manures in the first year when the differences in yields were inconspicuous.

Results During Four Years.

It will be noticed that not only did every plot which was treated with manure generally show an annual increase in crop, during 1903, 1904, and 1905, but also the control plot which was not treated with any manures whatever. During each year the stems and branches of the trees were examined carefully, and diseased tissues excised and burnt; during crop time the setting fruits were sprayed with copper sulphate and lime mixed together in water; this was the only treatment meted out in common to the trees on the control and manured plots. During 1903 and 1904 the limed plot, and those supplied with sodium nitrate, ammonium sulphate, basic slag and blood meal, and nitrate of potash, showed a large increase in yield over the control plot: during the same period the plots treated with fish, bloodmeal, and castor cake showed the minimum response.

The plots will require similar treatment for many years more before the results can be taken as being very reliable, but for cacao planters possessing soils similar to those previously described, the results obtained in four years may be of interest. The crop on all the plots at Peradeniya during 1906 was relatively poor, the wet weather towards the end of the year delaying the ripening of the fruits which had set. Only the most general deductions can be made from the results obtained at Peradeniya during the last four years.

GENERAL MANURES.

Acreage.	Plot No.	Manure applied.	When applied during each year.	Number of Fruits per 300 Trees.				Total.	Excess over Control Plot.
				1906.	1905.	1904.	1903.		
Acre.									
1 ...	8	6 cwt. of kainit. ...	January, May & August ...	5,045	9,645	5,768	3,733	24,191	+ 7,593
1 ...	9	5 cwt. bone dust. ...	January ...	5,104	8,924	6,064	3,572	23,664	+ 7,066
...	98	5 cwt. fish. ...	January and February ...	3,726	6,746	3,211	1,156	14,839	— 1,759
1 ...	110	250 lb. of basic slag buried with leaves and twigs. ...	March ...	7,780	11,109	3,227	4,038	26,154	+ 9,556
1 ...	6	Trenched and buried debris with 10 cwt. of lime; ground not forked. ...	January ...	5,587	9,129	6,740	3,266	24,722	+ 8,124
1 ...	5	Trenched and buried debris with 10 cwt. of lime, and forked all over the ground. ...	Do. ...	3,690	8,072	8,070	4,794	24,626	+ 8,028
1 ...	4	10 tons of cattle manure forked in around the trees in 1904. ...	Do. ...	3,161	9,853	9,326	6,475	28,815	+ 12,217
1 ...	3	1903. two tons of lime forked in, ... 1905, Crotalaria sown, pruned and forked in. ...	Do. October	4,243	9,994	10,222	8,684	33,143	+ 16,545

NITROGEN ONLY.

Acreage.	Plot No.	Manure applied.	When applied during each year.	Number of Fruits per 300 Trees.				Total.	Excess over Control Plot.
				1906.	1905.	1904.	1903.		
Acre.									
½ ...	95 A	Sodium nitrate (to determine the effect of excess of soluble nitrogen), 400 lb. per half acre ...	January, May, and August ...	6,713	10,973	9,727	3,448	30,861	+ 14,263
½ ...	95 B	Groundnut cake (to determine the effect of excess of relatively insoluble nitrogen), 896 lb. per half acre ...	January and May ...	4,475	8,335	7,929	3,445	24,184	+ 7,586
1 ...	99	Bloodmeal, 400 lb. per acre ...	Do. ...	4,810	8,666	3,300	1,018	17,794	— 1,196
1 ...	100	Castor cake, 833 lb. per acre ...	Do, ...	4,763	6,774	3,860	1,356	16,753	+ 155
1 ...	111	Ammonium sulphate 250 lb. per acre ...	March ...	7,789	10,474	6,595	4,038	28,896	+ 12,298

POTASH ONLY.

Acreage.	Plot No.	Manure applied.	When applied during each year.	Number of Fruits per 300 Trees.				Total.	Excess over Control Plot.
				1906.	1905.	1904.	1903.		
Acre.									
½ ...	94A	Potassium chloride (to determine the effect of excess) 107 lb. ...	January, May and August ...	5,995	10,754	8,221	3,143	28,113	+ 11,515
½ ...	94B	Potassium sulphate (to determine the effect of excess), 125 lb. ...	Do. ...	5,386	9,307	7,513	3,174	25,380	+ 8,782

PHOSPHORIC ACID ONLY.

½ ...	96A	Concentrated superphosphate (to determine the effect of excess), 141 lb. ...	January, May and August ...	5,893	10,955	7,538	3,575	27,961	+ 11,361
½ ...	96B	Precipitated phosphate (to determine the effect of excess), 163 lb. ...	Do. ...	5,668	7,893	8,312	3,454	25,327	+ 8,729

MIXTURES CONTAINING NITROGEN, POTASH, AND PHOSPHORIC ACID.

Acreage.	Plot No.	Manure applied.	When applied. during each year.	Number of Fruits per 300 Trees.				Total.	Excess over Control Plot.
				1906.	1905.	1904.	1903.		
Acre.		Phosphoric acid & Potash.							
1 ...	101	250 lb. basic slag & 100 lb. potassium sulphate...	February and May ...	6,194	8,221	5,423	3,248	23,086	+ 6,488
		Phosphoric acid & Nitrogen.							
1 ...	7	5 cwt. basic slag 200 lb. ammonium sulphate ...	January, May and August ...	6,241	11,340	6,877	3,323	27,781	+ 11,183
¾ ...	Tu. A	188 lb. basic slag & 300 lb. bloodmeal ...	March ...	8,251	7,196	8,112	4,955	28,514	+ 11,916
1 ...	109	114 lb. of nitrate of potash..	Do. ...	5,166	7,865	3,251	4,038	20,320	+ 3,722
1 ...	108	714 lb. groundnut cake and 100 lb. potassium sulphate. ...	Do. ...	4,964	8,324	4,987	4,038	22,313	+ 5,715
1 ...	107	250 lb. basic slag 833 lb. Castor cake & 100 lb. potassium sulphate. ...	Do. ...	4,989	8,654	4,028	4,038	21,709	+ 5,111
1 ...	93	Control plot ...	—	3,828	5,976	4,271	2,523	16,598	Control

Yields of Cacao in Tropical America.

Preuss states that the "Trinitario" was introduced by Hart to Nicaragua because it could be cultivated more easily and bore fruits in the fourth year, whereas the Nicaraguan-Criollo did not produce any crops until the sixth year. In Ceylon, however, it is worth recording that cacao plants obtained from Nicaraguan-Criollo trees, acclimatised at Peradeniya, flowered when they were only a little over three years old, and many would have set fruits had they been allowed to do so. Preuss states that though the Nicaraguan-Criollo is a much weaker type than the Trinitario, it will, with good cultivation, give higher yields than the latter. A yield of about 1 lb. of dry cacao per tree, per year, is considered to be near the average yield in Nicaragua.

In Ecuador the cultivated cacao trees begin to crop in their fourth year and produce full harvests in the sixth to the tenth year. Preuss states that the average yield is estimated to be about 1 lb. of dry beans, per tree, per year, which, when one considers how closely most of the estates are planted, must amount to a comparatively heavy harvest. Individual trees are said to produce an average crop of $1\frac{1}{2}$ to 2 lb. of dry beans, per year. The Arriba cacao is described as the best for aroma, taste, and contents, as well as giving good yields.

In Surinam an average annual yield of 1·5 kg. per tree has been recorded, and in good alluvial soils as much as 3 to 4 kg. per tree, per year, is often obtainable.

In Mexico, according to Jumelle, some plantations possess trees which yield from 5 to 8 pounds of cured cacao annually. Jumelle states that in the Antilles the yield is comparatively low. According to M. de la Valette the Xmas yield gives at the most $1\frac{1}{2}$ lb. per trunk, and that of Saint John, 1 lb., when the trees are 5 to 8 years old.

Yields of Cacao in the West Indies.

The following table shows the average yields obtained on various cacao properties in Trinidad, Grenada, and St. Lucia :—

Yield of cured cacao, per acre, in lb.		
612	...	... Trinidad (Jamaica Bul., Sept., 1905).
784	...	... Grenada. ,, ,, ,, ,,
343	...	... St. Lucia. (Manured).
482	...	... St. Lucia. ,,
765	...	... St. Lucia. ,,
300	...	... St. Lucia (1905-06).

YIELD OF CACAO IN THE WEST INDIES.—*Contd.*

Yield of cured cacao per acre, in lb.		
1½ to 1⅗ lb.	per tree	... Trinidad (Preuss).
464 crams	,, ,,	... ,, (Royal Commissioner).
2 to 3 lb.	,, ,,	... ,, (Olivier).
1·5 to 1·6 lb.	,, ,,	... ,, (Hart).
1·4 lb.	,, ,,	... ,, (Gannes).

YIELDS IN GRENADA.

In Grenada, where manuring with stable and vegetable compounds is said to be extensively carried out, the cacao trees begin to bear fruits in good quantity in their fifth year, and according to Preuss the yields obtained, though dependent upon the continuation of manuring operations, are higher than those quoted for Trinidad. The cacao trees are frequently planted very close, a distance of nine feet apart being often met with. The variety most cultivated appears to be of the Amelonado type, so that larger yields per tree, and per acre, can reasonably be expected than in those countries where the trees are more widely planted and of a less prolific but superior kind. On some estates in Grenada a yield of 4 bags, each weighing 196 lb., is said to be the annual outturn, per acre.

CACAO MANURIAL EXPERIMENTS AT GRENADA.

The following is the report* and account of cacao manurial experiments carried out at Grenada:—

"A, the pen manure section, is the wettest section of the plot, and it will be noticed that, notwithstanding the heavy application of manure in May, 1903, the yield fell below the two preceding crops, and only recovered after several rows of new drains had been added to those already existing—and dug diagonally across the slope. This illustrates the value of drains in a wet clay soil, without which manure is at a discount."

"The Potash section D has steadily advanced and, unlike sections B and C, which unaccountably fell off by ⅛ to ¼ bag, held its own during the crop 1902-3. The cost of production for the first two years averaged £1 per bag of cacao, and for the second two years 12s. per bag, or an all-round average of 16s. per bag for four years' working."

"When the results of the fifth year's working are known, the cost of production will be considerably reduced".

The following figures show the gradual improvement in yield:—

Crop 1900-1=5¼ bags per acre.
Crop 1901-2=7 ,, ,,
Crop 1902-3=7 ,, ,,
Crop 1903-4=8 ,, ,,

* Agricultural News, Vol. III., p. 347; and Trinidad Bulletin, No. 48, 1905.

"Full particulars are given in the following table as to the details of treatment accorded to the various sections":—

Section.	Manures applied (with dates).	Crop 1900-1.		Crop 1901-2.		Crop 1902-3.		Crop 1903-4.	
		Dry Cacao per sectional acre (pounds).	Bags per acre.	Dry Cacao per sectional acre (pounds).	Bags per acre.	Dry Cacao per sectional acre (pounds).	Bags per acre.	Dry Cacao per sectional acre (pounds)	Bags per acre.
A. ¼ acre.	June 1900: Pen manure, 3 baskets per tree, 15 tons per acre.	1,036	5⅝	868	4⅔	808	4½	1,184	6½
	May 1902: Do. (Extra drains dug, August 1902).								
B. ¼ acre.	August 1900: Basic slag, 8 cwt. per acre.	1,112	6	1,572	8½	1,512	8¼	1,648	9
	February 1901: Sulphate of ammonia, 1½ cwt. per acre.								
	May 1902: Basic slag, 8 cwt. per acre.								
	August 1902: Sulphate of ammonia, 1½ cwt. per acre.								
C. ¼ acre.	August 1900: Basic slag, 8 cwt. per acre.	888	4¾	1,324	7⅛	1,309	7	1,492	8
	February 1901: Nitrate of soda, 1½ cwt. per acre.								
	May 1902: Basic slag, 8 cwt. per acre.								
	August 1902: Nitrate of soda, 1½ cwt. per acre.								
D. ¼ acre.	August 1900: Basic slag, 8 cwt. per acre and sulphate of potash, 1 cwt. per acre, (mixed).	860	4⅔	1,472	8	1,488	8	1,612	8¾
	May 1902: Do.								

According to the report of McNeil, published in the Grenada Government Gazette, the following results have been obtained with various artificial manures :—

Manures.	Plots.					Total Weight of wet cacao in pounds.
	A	B	C	D	E	
Basic slag and sulphate of potash ...	522	279	340	1109	561	2811
Basic slag and sulphate of ammonia ...	426	252	252	1202	613	2745
Basic slag and nitrate of soda ...	251	200	307	1021	420	2199
Sheep or pen manure ...	362	148	218	657	493	1878

The immediate superiority of artificial manures appears manifest in these results, basic slag with sulphate of potash or sulphate of ammonia being apparently the best combinations.

Yields in Trinidad.

In Trinidad the cacao is more extensively cultivated than in Grenada, but the trees do not produce continuous and good crops, according to Preuss, until they are about ten years old. The average yield of cacao is said to be from 1·5 to 1·6 lb. per tree, and Preuss gives the following yields from one good estate in Trinidad compiled on the occasion of his visit to that country :—

Number of trees.	Age of trees.	Distances of trees.	Yield of cacao.	Yield of cacao per tree.
		feet.	lb.	lb.
4,019	20	12 by 12	10,300	2·5
1,250	17	12 by 12	4,450	3·5
2,382	10	10 by 10	5,400	2·3
1,080	25	12 by 12	3,600	3·3
918	10-12	12 by 12	3,150	3·4
2,770	20	12 by 12	7,100	2·5
4,416	6	12 by 14	3,425	0·77

According to the Royal Commissioner the yields on good estates in Trinidad amount to 280 kilos per hectare, or 464 grams per tree.

Olivier states that in Trinidad, the average yield throughout the island is about 600 lb. of cured cacao per acre, or about 2 lb. per tree, and points out that an average of 3 lb. of cured cacao per

tree, or 900 lb. per acre, must not be considered exceptional in good districts where proper cultivation is maintained. Hart calculates that on estates in Trinidad where the cacao trees are planted fifteen feet apart, a yield of 300 lb. of cured cacao per acre, per year, may be expected, each tree producing 1·6 lb.; on estates planted twelve feet apart a yield of 1·5 lb. of cured cacao is estimated. Gannes, at the West Indian Agricultural Conference, 1905, stated that a yield of 12 bags, each of 170 lb., per 1000 trees planted 12 feet apart, was a safe estimate; this is the equivalent of 1·4 lb. per tree, per year.

Cacao Manurial Experiments in Trinidad.

The following account has been published* of manurial experiments, concluded on the 30th June, 1905 :—

Results of Cacao Experiment Plots at La Vega Estate, Brasso, Hon'ble Carl de Verteuil.-July 1904 to 30th June, 1905.

Number of full bearing trees.	Manuring Treatment.		Expenses.		Wet cacao harvested in lb.		
	Per Plot.	lb. per tree.	Cost of Manures.	Cost of Cultivation.	Total.	Plot.	Per tree.
		1.	2.	3.	4.	lb.	
				$.c	$.c		
†A 235				11·59	11·59	1860	7·91
†B 215	Sulphate of Ammonia-400 lb.	1·86	18·72	15·64	34·36	1896	8·82
	Basic Slag-4 cwt.	2·08					
†C 224	Pen Manure-10 tons	1·00	4·80	18·88	23·68	1990	8·88
†D 216	Basic Slag-4 cwt.	2·07	8·08	15·64	23·72	2332	10·79
	Sulphate of Potash-1 cwt.	0·51					

Cacao Yields in St. Lucia.

The tables given elsewhere show what experiments have been made in St. Lucia with various natural and artificial manures and modes of tillage. Hudson ‡ states that an application of basic slag at the rate of 5 to 10 cwt. per acre applied in December or January, followed by 1 cwt. of sulphate of ammonia in the following August or September has given the best results in St. Lucia and also in Grenada with cacao in bearing; bone meal is also recommended for the young plants, about half a pound being mixed with the soil before filling in the holes.

* Trinidad Bulletin, No. 48, 1905.

† Plots A, B, C, and D. contain approximately one acre.

‡ G. S. Hudson, Agricultural News, Barbadoes, Oct, 1901.

§ Report of Botanic Station and Experimental Plots, St. Lucia, 1903-1904.

RESULTS OF CACAO EXPERIMENT PLOT AT ST. LUCIA FOR THE YEAR ENDING MARCH 31, 1904.

Name of Plot.	Acreage.	Number of bearing trees.	Tillage operations employed.	Cost of Tillage.	Manurial treatment employed (with dates.)	Cost of manure.	Total cost of Plot.	Yield of dry cured Cacao.	Remarks.
	Acre.			£. s. d.		£. s. d.	£. s. d.	lbs.	
Soufrière	1	250	Weeded five times. Forked and supplied. Removed suckers as necessary. Removed part of banana shade.	2 11 7	April 1st, 1900, 10 cwt. basic slag. August 6, 1900, 1 cwt. sulphate of ammonia.	3 8 5	6 0 0	343	Applied 20 cart loads of village street refuse in Dec. 1903.
Dennery	1	300	Weeded four times. Forked and supplied. Removed suckers as necessary. Planted bananas and immortels for shade.	2 10 11	April 1, 1903, 8 cwt. basic slag August 27, 1903, 1 cwt. sulphate of ammonia.	2 18 5	5 9 4	482	This is a new plot on St. Joseph's estate, taken over April 1, 1903, the old plot on Beau Sejour estate having fulfilled its purpose.
Roseau	1	350	Weeded twice. Forked and drained. Removed suckers as necessary.	2 8 0	April 1, 1903, 8 cwt. basic slag. August 22, 13, cwt. sulphate of ammonia.	1 4 1	4 2 0	765	Cost of manure should be £2 19s. 1d., an additional £1 15s. being included in accounts for previous financial year.

Results at St. Lucia.

The following results of crop records and manuring for the past eight years on Errard estate are given in the Reports on Experiment Stations, St. Lucia, 1904-5:—

Plantation No.	Area.	Unmanured six years (1897-98 to 1902-03) average yield of cured cacao per acre.	Manure applied 1903-04 per acre.	Cured crop 1903-04 per acre.	Manure applied 1904-05 per acre.	Cured crop 1904-05, nine months only, per acre.
	acres.	lb.		lb.		lb.
1	2	476	7 cwt crushed bones. 5 tons stable manure.	1,316	4 cwt. basic slag. 3 tons stable manure. 1 cwt. sulphate of ammonia.	1,412
3	10	460	8 cwt. basic slag. 1 „ sulphate of ammonia.	711	4 cwt. basic slag. 1 „ sulphate of ammonia.	847
13	5	381	8 cwt. basic slag. 1 „ sulphate of ammonia.	752	4 cwt. basic slag. 1 „ sulphate of ammonia.	825
14	1	333	6 cwt. Arnotts' cacao manure.	794	Nil.	650
15	20	244	Nil (pruned and drained only)	296	8 cwt. basic slag. 1 „ sulphate of ammonia.	396

The following details of the cacao manurial experiments on the Soufrière and Roseau plots, St. Lucia, are given by Hudson, in his 1905-1906 Report :—

Soufrière Plot, La Perle Estate.

Year.	Acreage.	Yield of cured cacao.	Manures applied.
1901-02	1 acre	217 lb.	1 ton sheep manure.
			1½ cwt. sulphate of ammonia.
1902-03	,,	236 ,,	2 cwt. sulphate of potash.
1903-04	,,	343 ,,	10 cwt. basic slag.
			1 cwt. sulphate of ammonia.
			3 tons stable manure.
1904-05	,,	717 ,,	4 cwt. basic slag.
			1 cwt. sulphate of ammonia.
			10 tons village street refuse.
1905-06	,,	1081 ,,	4 cwt. basic slag.
			1 cwt. sulphate of ammonia.

Roseau Plot, Bellair Estate.

Year.	Acreage.	Yield of cured cacao.	Manures applied.
1901-02	1 acre.	360 lb.	8 cwt. basic slag.
			1 cwt. sulphate of ammonia.
1902-03	,,	650 ,,	2 cwt. sulphate of potash.
1903-04	,,	765 ,,	8 cwt. basic slag.
			1 cwt. sulphate of ammonia.
1904-05	,,	580 ,,	4 cwt. basic slag.
			1 cwt. sulphate of ammonia.
1905-06	,,	450 ,,	2 cwt. sulphate of potash.

Hudson concludes that potash should not be applied in excessive quantities, and believes that ½ cwt. per acre is sufficient to apply at one time; he also states that phosphoric acid and lime should always be applied to cacao soils.

Manurial Experiments in Dominica.

The methods adopted on cacao estates in Dominica have been largely influenced by the results obtained by Watts, and a summary of the principal experiments is given below :—

Yield of Wet Cacao in Pounds.

No. of trees per plot.	Manure.	1903.		1904.		1905.		1906.		Mean of four years.		Difference on no manure.	
		per plot.	per tree.	per plot	per tree.	per plot.	per tree.	per plot.	per tree.	per plot.	per tree.	per plot.	per tree.
34	No manure ...	759	22·3	548	16·11	673	19·76	748	22·0	682·0	19·97	—	—
37	Basic phosphate 4 cwt. per acre. Sulphate of potash 1½ cwt. per acre.	1,063	28·7	808	21·83	814	22·00	763	20·62	862·0	23 13	+180·0	+3·16
40	Dried blood 4 cwt. per acre ...	1,281	32·2	970	24·25	970	24·25	1,056	26·4	1,069·7	26·64	+387·7	+6·67
34	Basic phosphate 4 cwt. per acre. Sulphate of potash 1½ cwt. per acre. Dried blood 4 cwt. per acre.	1,104	32·4	738	21·70	979	28·79	1,040	30·59	965·2	28·12	+283·2	+8·15
39	Mulched with grass and leaves ...	1,145	29·3	962	24·60	1279	32·79	1,519	38·94	1,226·2	31·20	+544·2	+11·23

The above results have been obtained by Watts* at Dominica, and that chemist concludes that it is essential that those methods, which, in the tropics, lead to the conservation of humus or vegetable matter in the soil, are of the first importance, not only with cacao trees in bearing but also with young plants. The results have been brought up-to-date† and the averages calculated from the figures available. The mulch was composed of cut grass, the result of mowing the lawns, and the leaves falling from the trees around the lawns, principally *Pithecolobium saman.*

* Reports on the Experiment Plots, Dominica, 1904-5.

† West Indian Bulletin, Vol. VII., No. 3, 1906.

CHAPTER XV.

DISEASES OF CACAO PLANTS.

Cacao Diseases in Various Countries.

THE number of diseases recorded from countries supplied with Botanic Institutions possessing mycologists and entomologists is at first sight alarming. There are countries where, though cacao has been cultivated for many years, the records of specific diseases are very scanty; usually the diseases are in existence in such places, but have not been identified on account of the absence of officers engaged in such research. Preuss, in his tour through South and Central America, records that in Ecuador he observed *Phytophthora omnivora* on the cacao fruits, and that squirrels, monkeys, ants, and woodpeckers did considerable damage. He also reported that the diseases affecting cacao in Surinam were similar to those found in Cameroon: *Phytophthora omnivora* plays havoc with the fruits, the larvae of several stag beetles (Steirastoma) bore into the stem and branches, and root diseases are frequently indicated; the krulloton disease is also often bad. Compare these with the records of the Government Botanist, * British Guiana, who states that in the list of the more important fungus and insect diseases, may be mentioned;—

(1) Cacao pod disease, *Phytophthora omnivora*, De Bary; (2) Brown rot disease, *Diplodia cacaoicola*, P. Henn.; (3) Witch Broom disease, *Exoascus theobromæ*, Ritz Bos.; (4) Thread disease of cacao; (5) Excresences of cacao trees; (6) Thrips, *Physopus rubrocincta*; (7) Cacao beetles, Steirastoma sp.; (8) "Leaf miner" of cacao pods.

Java has also recorded the occurrence of several pests among which may be mentioned the cacao canker † of the stem of older trees, the so-called "Djamur upas" sickness, due to a fungus which kills the young branches and causes a blackening of the fruits. Damage is also caused by the caterpillars of a little moth which bore through the fruits, and by various larvae of butterflies and beetles.

Within recent times several diseases have been reported on the cacao plants in Samoa, ‡ which have had a discouraging effect on

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* Official Gazette, Demerara, July, 1905.

† Die Kakaokultur und der Kakaohandel Niederlandisch-Indiens; Der Tropenpflanzer, No. 8, August, 1904.

‡ Gefahrdung der Kakaokultur auf Samoa, by Dr F. Reinecke, Der Tropenpflanzer, 1902, p. 632.

those interested in this product. Owing to the official rules forbiding the importation of other seeds or plants from countries where diseases are prevalent, and the combination among the planters to combat the various pests, the industry is expected to show considerable improvement in the future.

If to these lists be added the names of the fungi collected and examined by Hart, Lewton-Brain, Howard, and Stockdale, in the West Indies, by Carruthers and Petch in Ceylon, and the insect pests described by Maxwell Lefroy and Green, an unpleasant array of pests is before the prospective cacao planter. It is, however, very satisfactory to know that all the diseases of the cacao plant can be checked, and the knowledge available is a help and not a bogey to the cultivator in the tropics.

Cacao Diseases: Conditions for, and Curative Measures.

Cacao has been planted over large acreages, and for a considerable length of time in various parts of the tropics; it is not one of the hardiest of the cultivated products, and though it is capable of recovering from the effects of most pests, the ravages of fungi and insects on many parts of the plant have often led to much anxiety and financial loss. In Trinidad the uninterrupted spread of disease was, in 1727, responsible for the death of a great portion of the cacao then under cultivation, and a period of thirty years elapsed before any serious attempt was made to revive the industry. Ceylon, prior to the work of Carruthers, was at one time in a bad state with cacao diseases, and many planters, even to-day, have a faint belief in the spreading of recurring and devastating epidemics at more or less irregular intervals.

Conditions for Spread of Diseases.

The diseases which affect the stems, branches, and fruits of cacao in the east and west are dangerous if allowed to grow unchecked, but the stages and favourable conditions for the growth of the parasites now being more or less known, effective remedial measures have been brought forward in every cacao-growing country of repute. The most dangerous fungi usually thrive best under conditions of dense shade and abundance of moisture, and rapidly spread through the stems and fruits. The rapidity with which the cacao parasites effect their devastation is obvious from the fact that at the Experiment Station, Peradeniya, Ceylon, the yield of cacao from diseased trees was reduced from 330 to 66 pounds per acre, per year, in six to seven years from the first conspicuous appearance of the disease. The check to the yield was due to diseases on the stems, branches, and fruits, and, at the time the curative methods were taken in hand, as much as 96 per cent. of the trees and 14 to 62 per cent. of the fruits were attacked. The rapidity of the recovery, however, was more conspicuous than the development of the disease, as within three years of commencing plant sanitation operations, the yield was increased from 100 to 400 pounds per acre, per year.

Sanitary Measures Necessary.

There are many ways by means of which the diseases can be kept in check, but briefly they are as follows:—

1. Letting in sunlight.
2. Excision and burning of diseased tissues on the stem.
3. Frequent collecting and burning of diseased fruit or burying with lime.
4. Spraying with chemical compounds known to be poisonous to the spores of fungi or to injurious insects.
5. Collecting and destroying all injurious insects.

These operations will be dealt with later.

It is agreed by all scientists who have worked on this subject in the tropics that the known diseases affecting cacao under cultivation can be kept in check, and in Ceylon it has been definitely proved that when the diseases have developed almost to the maximum, they can still be attacked with a prospect of being reduced to a minimum, within three years, on an expenditure which is made good within that period. There is, therefore, no reason why, on cacao properties still diseased, curative measures should not be immediately and continuously carried out.

Results Obtained in Ceylon.

The remedial measures which are described in the following pages have been proved effective in Ceylon, and the accompanying illustration will help to make the case in point more striking. In 1902 the cacao was very badly diseased, as much as 96 per cent. of the trees and 14 to 62 per cent. of the pods collected being attacked by the fungus. The curative methods herein described were commenced in May, 1902, and within six months an improvement was obvious. In 1902 the percentage number of fungus pods was 35; in 1903 this was reduced to 7 per cent.; in 1904 to 4 per cent., and in 1905 to 2·3 per cent., by an expenditure which was more than covered by the value of the increased crop. In 1902 the crop was only 0·83 cwt. per acre; in 1903 it rose with a decrease in the disease to 1·18 cwt.; in 1904 to over 2 cwt., and in 1905 was no less that 3·57 cwt. per acre.

Relation Between Rainfall and Disease.

There can no longer be any doubt as to this relationship. During June and July in 1904 we had no less than 29·56 inches of rain, and canker work was almost at a standstill. During this period the mycelium was growing as quickly as it possibly could, and the large expenditure incurred in August and September for excision work alone, as compared with the previous months, was sufficient proof of the rapidity with which the fungus had spread. The heavy rainfall occurred during months when very little mature fruit was on the tree. The maximum percentage number of fungus

pods in July and August was associated with the heavy rainfall during June and July.

The diseases which are known to affect parts of the cacao plant in the tropics will now be dealt with under the separate headings of leaf, stem, fruit, and root pests.

Stem Diseases : West Indies.

Fungi.—In the islands* of Trinidad, Grenada, St. Lucia, and Dominica the stems and branches are attacked by fungi among which the more notable are, according to Lewton-Brain, *Nectria* species and *Diplodia cacaoicola*. The "canker" of the stems and branches, recognised by exudations from, and discolouration and softening of, the affected parts, is assumed to be due to a species of *Nectria*, but whether this is identical with that in Ceylon does not appear clear. The disease spreads in all directions and the fungus causing it is regarded as being a wound parasite by Lewton-Brain, who in his recommendations for eradication suggests that the first measure is "to care for wounds, both those made in pruning and accidental ones; knives or cutlasses, that have been used in cutting out diseased wood, should be cleaned before being used for pruning other trees. Wounds should be thoroughly tarred over. In pruning, care should be taken to cut close to the main stem and to leave a smooth, sloping surface. Dead trees should be cut down to the ground and the wood burnt. All dead branches and twigs should be removed or destroyed, not allowed to lie about on the ground and rot there. If taken in the earliest stages, the diseased bark and wood may be cut out with a sharp knife, taking care to get rid of all diseased tissue. The wound should be tarred over".

Diplodia cacaoicola is a fungus met with in some parts of the West Indies, where it starts in the young twigs and spreads to the large branches, leaving behind dead tissue. According to Lewton-Brain the spores of this fungus are formed in chambers in the bark, and break through as black spots; the fungus does not readily attack healthy vigorous trees, and may live on dead wood. The measures to be taken involve good cultivation, removal and destruction of all dead wood, and tarring of well-trimmed wounds.

According to Morris and Howard† a "canker" on the stem in Trinidad, Grenada, and Dominica may be due to *Nectria theobromæ*, Massee, or to *Calonectria flavida*, Massee, or to both.

Stockdale‡ has recently reported the occurrence of the mycelium of a fungus in the tips of dying cacao branches in Trinidad, but has not yet identified the parasite. The symptoms are a drooping and reddish colouration of the leaves followed by a dying back of the

* West Indian Bulletin, Barbadoes, Vol. VI., No. 1, 1905.

† Bul. Misc. Information, August, 1901, Trinidad.

‡ Cacao Disease in Trinidad, Agricultural News, August 25th, 1906, Barbadoes, by F. A. Stockdale.

tips of the branches, which spreads downwards rapidly and results in a general decay of the branch. Stockdale states that in some twigs it was also noticed that a small insect had entered through the bud into the pith of the wound stem. In order to check the spread of the disease it is recommended that all affected parts be pruned and burnt.

Stem Diseases: Ceylon.

Fungi.—The attention of Ceylon planters to the cacao disease on the stem was first prominently given in February*, 1897, and Carruthers was subsequently placed in charge of the investigation to determine the life-history of the fungus and to frame remedial measures. The results recorded by Carruthers† have been made known, and the spread of the disease appreciably checked in Ceylon; the fungus causing the disease on the stems and branches in Ceylon was referred to the genus *Nectria*, and no mention has yet been made, in Ceylon official publications, of *Diplodia cacaoicola* as occurring on the vegetative parts of cacao in Ceylon.

Symptoms of Canker.

The external signs of cacao stems and branches attacked by the "cacao canker" are a general lack of vitality, dying back of branches, and a reduction in the crop. The affected areas on the stem or branch present, in their early stages, the appearance of moist spots, which, on account of their relatively dark colour are readily observed on the bark; on excising such an area, the diseased bark is seen to be of a brownish or reddish colour, and contrasts markedly with the paler colour of the healthy bark. When the disease is allowed to develop freely, the affected area increases in size, becomes darker in colour, and frequently a gummy exudation appears on the surface; old diseased areas are very soapy to the touch, and are often subject to the attacks of borers. These parts possess the mycelium of the parasitic fungus causing canker.

The mycelium of the fungus spreads rapidly in all directions through stems and branches, and continuity of diseased tissue is frequently observable between the peduncles or stalks of the fruits and the bark of the stem; if allowed to grow without interruption the mycelium sooner or later ramifies completely round the bark, and the parts of the stems and branches above the area affected ultimately die. The cacao tree appears to be able to live for several months or even years, though the fungus is always present in its tissues; when the shade is dense or the moisture excessive the mycelium spreads very rapidly. The spore-producing chambers of the fungus appear on the surface of the bark as white or pinkish patches of pustules; the spores become free and are carried about by the wind, rain, clothes, etc.

The fungus attacks trees of the Caracas, Amelonado, and Forastero varieties irrespective of their age, and under all conditions

* Circular, R. B. G., Peradeniya, Series 1, No. 2, 1897.
† ,, ,, ,, ,, 1, No. 23, 1901.

of climate and soil. Some varieties of cacao renew their diseased areas, after excision, quicker than others, but none are immune from the attacks of this parasite. This disease is one of the most serious pests on cacao in Ceylon, and a detailed account of practical methods adopted to keep it in check is therefore given.

Excision and Burning of Diseased Bark.

The excising and burning of all diseased areas, even when the mycelium has penetrated into the wood, is necessary; this, together with the burning of the dead branches—whether killed by the fungus or not—has been very effective in Ceylon. This excising of cankered areas is best carried out in the dry weather, when plenty of labour is available, and flowers and fruits are present in the minimum quantity. It is far more important that this work should be carried out than that money should be spent in spraying fruits, coating diseased areas of the stem with tar, or washing them with strong acids and alkalies. The use of the knife is effective in combating the disease on the stems and branches, and on most Ceylon estates is the only curative measure adopted. It is obvious that the examination and treatment of the stem for disease is the most important item to be reckoned with in the cultivation of cacao in Ceylon, as, if the fungus is allowed to develop, reduction in crop followed by the death of the trees, is a certainty.

Objections Against Excising Diseased Tissues.

Several examples are known where areas of cacao have never been treated for disease, and which have more or less successfully withstood the ravages of the fungus; it is the existence of such local circumscribed patches which has formed the butt of the arguments of the few anti-canker planters. Let us then examine the pros and cons of this curative method. The first and most serious argument against carrying out this work is that of expense. Experience has convinced us that on a cacao property which had been neglected for several years, and which had almost every tree affected by the fungus, an expenditure of Rs. 17 per acre was required for the first year, and an annual recurrent expenditure of from Rs. 8 to Rs. 12 for each succeeding year if the canker was to be kept in check. It is difficult to understand why cacao planters should ever object to such an expenditure, when at the same time they allow sums of Rs. 8 and even more, per acre, per year, for the weeding of cacao estates. It is not in the province of this chapter to deal with suggestive methods of cultivation for reducing the evil effects of weeding, but mention is made of this work to show that expenditure cannot logically be the only objection against the excising and burning of diseased tissues, and to point out that expenditure on weeding in preference to canker work is probably against the interests of the industry.

A second objection often put forward is that the work of excising and burning cannot be kept up throughout the year, and

therefore the rapid spread of the fungus during the wet months may mitigate any good effects that might be accomplished during the dry part of the year. It is perfectly sound to assert that the adoption of excision work for a couple of months in the year is not followed by the best results; but it has yet to be proved that the weather conditions prevailing in cacao-growing districts are against the execution of this work except during the dry season.

Generally speaking, the months of June, July, October, and November are too wet for effective canker work, and the labour is urgently required for planting or picking operations. But during the other months in the year there is usually a large number of fine days when canker work can be done, and it is satisfactory to know that several cacao planters carry on the curative work during every month of the year if possible. If the canker work is not systematically continued during the dry weather of most months of the year, the expenditure is to some extent wasteful; it can be shown that estates, which were so free from disease as to cost only 50 cents per acre per round, required after an interval of two months, approximately Rs. 2 per acre per round. The frequent inspection of the trees prevents the fungus from obtaining too firm a hold, and greatly reduces the cost per acre per round.

A third objection is that the coolies, by repeatedly scraping the stems with their knives in search of canker, aid the spread of the fungus spores. This may be an unavoidable evil, but it cannot be more serious than the carrying of spores on the clothes of the coolies, by animals or by the wind, and can never form a sound enough reason for the cessation of the use of the knife. The best proof against this or any other objection is to be seen on any cacao property where excising and burning are efficiently carried out, as in all these cases not only are the fungus trees greatly reduced in number, but the percentage of black pods is much smaller, and the crop is increased in quantity and quality far above the expenditure involved in executing the curative work.

Letting in Sunlight.

The power of the sun's rays in checking the ravages of many plant diseases has long been acknowledged. It would be difficult to find a better case in support of this than has been obtained with cacao in Ceylon. Dense shade on old cacao estates is usually correlated with the presence of the fungus disease, and examples can be quoted to show that if the other curative methods are adopted and sunlight not allowed to enter the trees, the disease is, after a period of three years, as bad, if not worse, at the end than at the beginning. As a case in point it may be quoted that on one area where the excising, collecting, and burning of cankered tissue was subsequent to the thinning-out of the shade, the yield of the cacao has been increased from 1 cwt. to approximately 5 cwt., per year. On an adjacent area where the shade was allowed to remain dense, but the other curative methods adopted, the yield remained almost

stationary, the increase being only in this case from 3/5ths to 1 cwt. per acre, per year. The letting in of sunlight, such as results from judicious thinning-out of shade, often prevents the spores of the fungus from successfully germinating and growing, and aids the tissues of the stems in their efforts to heal the wounds created by the excision of cankered areas.

Renewal of Excised Areas.

When a diseased patch of bark and wood tissue is removed the wound gradually heals from all sides, but usually most rapidly from above downwards; experiments have been made to determine the extent to which the ringing excision of "bark" can be carried on without killing the tree. It is well-known that "bark" may be cut away along one side of the stem for a distance of several feet, and the cacao plant will continue to live, and in time perhaps entirely fill up the gap with new tissue. If, however, the bark has to be cut around the stem, the connection between the upper and lower parts is severed, and the plant may or may not survive. It is therefore useful to know exactly what width of a ring of tissue can be removed without killing the tree, (1) when the cambium is removed, and (2) when the cambium is allowed to remain intact.

The following are the results of experiments carried out at Peradeniya:—

Series A.—Bark, phloëm, and cambium removed on 27th. January, 1903.

(1) Circumferential cut 1 mm. in width.—The cut was made into the wood all round the stem. On the 4th. of March a protuberance of tissue appeared from the margin of the upper cut end and continued to grow, and by the 28th. July the wound was completely healed. The original wound now shows as an annular protruding mass of periderm 3 mm. wide. No evil results followed this treatment.

(2) Circumferential cut 2 mm. wide.—On the 28th. July the greater part of the wound had healed. The upper part of the tree remained vigorous, and suckers appeared on the lower part.

(3) Circumferential cut 5 mm. wide.—The ring of tissue up to the wood was removed. The exposed wood was also scraped in order to destroy any possible remnants of cambium. On 4th. March the tissue from the margin of the upper cut end had grown to meet the surface of the lower cut. On 5th. August the wound was healed nearly all the way round, and no part of the tree had suffered.

(4) Circumferential cut 10 mm. wide.—This tree was treated as in the other cases, care being taken to destroy all the cambium. The protuberance of tissue from above was conspicuous on the 24th.

of March, but the gap was not entirely filled at the end of July. The width of this gap is about the maximum that can be allowed with certainty of not killing the upper part of the tree.

(5) Circumferential cut 25 mm. wide.—There was a good development of tissue from the margin of the upper end, but this was never large enough to fill up the gap. The upper part of the tree died.

These experiments proved that one cannot cut out a ring of tissue, through the bark, phloëm, and cambium to the young wood, of any considerable width without causing the death of the upper part of the tree. Circumferential cuts can be made up to 10 mm. wide without very serious effects, but if the cut is 25 mm. (equal to one inch) wide, upper parts of the tree will probably die.

This must be borne in mind when the canker has got nearly or completely round the stem at a particular level. Whenever possible a small narrow strip of tissue should be left to join the upper and lower parts of the tree. If the cambium forms a strip of tissue only 3 or 4 mm. wide, it will produce new tissue on both sides and thus tend to heal the wound. The success, which has followed several cases under observation, has been so satisfactory that this system has been adopted even when the remaining strip has been diseased, the diseased tissue being very lightly shaved and carefully examined on the successive rounds.

Series B.—Bark and phloëm cut around the stem without touching the cambium:—

(1) Bark and phloëm lightly shaved around the stem to a width of over 40 mm.

(2) Bark and phloëm shaved deeply around the stem to a width of over 40 mm.

In both cases the upper parts of the tree remained in a vigorous, condition even though in experiment (2) the excision was made as near as possible to the cambium. These prove that superficial shaving, or even deep shaving, may be carried on with wider gaps of tissue providing the cambium is not destroyed.

Washes for Canker.

In recent times several planters have been treating cankered areas on the stem with various reagents. The usual method is to lightly shave the bark and apply a particular "wash" to the claret-coloured area of the disease, with the object of destroying the fungus in such areas. The advantages of destroying the cacao fungus by such means are obvious to any one who has had experience in cacao canker work. Trees of the Forastero type have often fluted stems and many crevices, which form centres for the lodgment of spores, and it is impossible to excise the cankered

tissue in such parts without seriously mutilating the stem. A badly cankered tree, fluted and creviced at all points, requires an hour or more of a cooly's time if all the diseased material is to be cut away. If "washes" were really effective, the treatment would be attended with far less cutting away of healthy tissue, and a great saving of the plant, and of labour, would be achieved.

Several estates have been visited where "washes" were being tried, and in most cases it was obvious that much more powerful and effective reagents exist than those which were in use. The effect of strong acids and alkalies is interesting. Strong cold sulphuric acid is very rapid in its action, the cankered areas changing, almost instantly, from claret-red to pale-brown, and finally to the colour of the neighbouring healthy bark. This reagent dissolves the walls of the fungus, and completely destroys the parasite whenever the two are brought in contact; great heat is developed as soon as the reagent mixes with the water in the wet tissues of the stem. Strong cold nitric acid, and caustic soda are similar in their effects; but hydrochloric acid and acetic acid are much less powerful. By means of the first-mentioned reagent the cankered tissue can be made to work itself out within four hours after the application.

In all these cases, however, one cannot guarantee that the slender threads of mycelium leading in all directions from an area of infection will be killed. In some cases they are to all appearances destroyed, but in others the effect is superficial only. The treatment cannot be recommended except as experimental, and then only when conditions allow at least monthly inspection of all areas so dealt with.

Costs and Results.

At the Experiment Station, Peradeniya, in addition to letting in sunlight, and excising and burning diseased stem tissues, the fruit diseases have received attention. The cankered trees have been reduced from 96 to 5 to 10 per cent. Within a few years the expenditure has been reduced year by year, and the cacao crop considerably increased.

Cost of Excision and Increase in Crop.

Year.	Cost of excising and burning diseased tissues, per acre.	Percentage number of diseased trees.	Yield of cured cacao per acre, in cwt.
1902	12·00 (May to Dec.)	96	0·83
1903	17·39	10	1·18
1904	12·15	8	2·07
1905	9·61	6	3·57

Stem Diseases: West Indies.

Insects.—Beetles*, known as *Steirastoma depressa* and *S. histrionica*, attack the stems of cacao trees in the West Indies. The eggs are deposited in crevices of the bark, and the larvæ bore into the wood and do much damage. The larvæ may be destroyed by probing the holes with sharp implements or by poisonous liquids.

Steirastoma depressa has, in Martinique, done considerable damage by boring into the wood of young and old plants. The presence of the insect may be detected by the gummy exudations which occur wherever the pest has been at work. Thierry recommends catching the mature insect which occurs abundantly on fresh cacao husks heaped in the field; he also recommends syringing the holes made by the borer with carbon bisulphide and stopping them up. He points out that in districts in which the destruction of birds is forbidden the damage is far less, and suggests the preservation of insect-eating birds as an excellent course to adopt against *Steirastoma depressa*.

An ant, *Æcodoma cephalotes*, commonly known as the "Parasol Ant", often does considerable damage, but may be destroyed, according to Hart, by putting a dose of coal tar into its nests or by fumes of sulphur.

Species of *Aphides* and wood ants often do harm, not only by their presence, but indirectly as carriers of spores of parasitic fungi from one part of the estate to another.

Cameroon.

A bark louse† is reported on the bark of cacao trees in Cameroon. It has seriously attacked 35 to 40 per cent. of the cacao trees on the Moliwe estate, and over one thousand three-year-old trees have been cut below the crown in order to check the spread of the pest to healthy parts of the tree. Very little seems to be known either of the life-history of the pest or the remedial measures which will be most effective.

Among the more recent insect pests attacking cacao plants in Cameroon is a bug, identified by Kuhlgatz as *Deimatostages contumax*. This pest appears to be most active during the dry season and Strunk‡ has carried out numerous spraying experiments with chemical reagents commonly supposed to be useful as insecticides; reagents such as 2 per cent. solution of acetic acid, and 1, 2, and

* Revue des Cultures Coloniales. No. 52, May. 1900. also Ein Feind de Kakaobaumes, page 625, Der Tropenpflanzer, December, 1900.

† Rindenlaus im Kakao in Kamerun, Der Tropenpflanzer, p. 144, Vol. VI., 1902.

‡ Der Chemischen Mittel zur Bekämpfung der Rindenwanze des Kakaobaumes in Kamerun, by Dr. Strunk. Der Tropenpflanzer, November, 1906, p. 726.

3 per cent. solutions of lysol, were found to be of little use; others, such as soap, quassia, tobacco juice, petroleum with dextrine and compounds of arsenic are described as being very effective. Arsenical compounds may be used alone or mixed with soap solutions; soap solution of 3 per cent. strength or less is effective when applied alone and also forms a useful mixture with quassia, or an ingredient or mixtures containing petroleum, soda, etc.; tobacco juice or ordinary soap solutions are easily obtained, and if applied at the beginning of the dry season before the insects have become conspicuous are very effective.

Stem Diseases: Ceylon.

Insects.—Cacao branches are often infected by the lac insect* (*Tachardia albizziæ*, Green). In some cases the branches die back, but in others the trees look healthy. It affects individual trees—year after year—without spreading to the surrounding cacao, and, according to Green, does not appear to do very much harm to the affected tree itself, though the tips of a few twigs may occasionally die back in consequence.

A wood borer, known as *Monohamus fisculator*, frequently occurs, especially in association with cankered areas on the stem. Excising and burning are effective remedies, and blocking the entrance with coal tar has also been recommended. *Sesia flavicaudata*, Hmpsm., has been found in some samples of diseased cacao bark at Peradeniya.

Termites have been observed by Green to eat away the bark at the base of young plants, together with a small proportion of the wood; the upper parts of the cacao plants died.

Fruit Diseases: West Indies.

Fungi.—In the West Indies the fruits are said to be attacked by a fungus—*Diplodia cacaoicola*—which also attacks the stem, and by another called *Phytophthora omnivora*.

Diplodia cacaoicola, P. Henn., which as we have already seen causes a dying back of the twigs and branches, produces, according to Howard, the disease of the fruits know as "Brown Rot." The disease appears on any part of the fruit wall, and gradually spreads from a circular brown spot to the whole of the fruit; the latter ultimately becomes black and covered with pustules of the fungus spores. As this fungus can thrive on dead wood, living branches or fruits, it is obvious that the curative methods to be adopted are numerous; all dead and diseased tissues, whether of branches or fruits, should be burnt, and empty or shelled fruits not allowed to lie on the ground. This disease has been known since 1895 from German West Africa.

* E. E. Green, Tropical Agriculturist and Mag. C.A.S., Colombo, Oct., 1905.

Phytophthora omnivora, De Bary, reported from Trinidad, St. Lucia, British Guiana,* and Surinam,† is described by Lewton-Brain as covering the fruits with a white mycelium, which rapidly spreads to the interior of the fruits, producing a black colour, followed by decay. The mycelium produces conidia on the surface, from which spores are liberated and subsequently distributed by wind and rain; it also produces resting spores inside the fruits, which are only liberated when the fruit wall is broken. Burning the diseased or spraying the healthy fruits is recommended for this disease. Quite recently‡ the attention of West Indian cacao planters has been prominently called to this disease which in districts appears to be spreading rapidly.

This fungus is able to live on very many kinds of plants, and the spores affecting cacao fruits are not necessarily derived from diseased fruits of the same tree; all host plants should be determined and destroyed.

Nectria bainii,§ Massee. It is reported that this fungus attacks the fruits (Hart) only in the West Indies, though one of the same genus has been recorded on the stem of cacao in Ceylon.

Fruit Diseases: Ceylon.

Fungi.—According to Petch‖ a parasitic fungus has been found on the fruits of *Hevea brasiliensis* similar to that which causes the decay of cacao pods; the fungi causing the latter are *Phytopthora omnivora*, recorded¶ on Ceylon cacao in 1901 by Carruthers, and *Colletotrichum incarnatum*, Zimm., observed by Petch on unsprayed cacao fruits at Peradeniya. Carruthers also recorded a *Nectria* sp.? on cacao fruits in Ceylon.

It has long been known that when a fruit is diseased near the base or stalk, continuity of diseased tissues belonging to the fruit and bark of the tree may exist. Carruthers, by means of inoculation experiments claims to have proved that a disease, started on the fruit wall, may spread to the bark of the tree: many cases have been observed where a diseased fruit and the part of the bark with which it is in contact are infected, and also where the base of the fruit appears to become infected by diseased tissues in the stem. It therefore appears probable that in Ceylon there is a disease which may become common to both fruits and stems, but the species of fungus which is know to occur on both these parts of the cacao tree in the West Indies has not yet been recorded for Ceylon, and the matter presents some complication.

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* Lewton-Brain, l.c.

† Hart, l.c.

‡ Bull. Dep. Agr., Jamaica, December, 1905.

§ Kew, Bulletins, Jan. and Feb, 1899.

‖ T. Petch, Tropical Agriculturist and Mag. C.A.S., August, 1905.

¶ Carruthers, R.B.G. Circular, No. 23, 1901.

In order to make this matter clear the following table is drawn up, showing the more notable fungi recorded on cacao trees or their parts in the West Indies and Ceylon.

Ceylon and the West Indies.

	Stems and Branches.	Fruits.
West Indies ...	*Diplodia cacaoicola*	*Diplodia cacaoicola*. P. Henn.
	Caloncctria flavida, Massee.	*Phytophthora omnivora*, De Bary.
	Nectria theobromae, Massee.	
	Canker fungus (Nectria ?)	*Nectria bainii*, Massee.
Ceylon ...	Canker fungus (Nectria ?).	Canker fungus (Nectria ?). *Phytophthora omnivora*. *Colletotrichum incarnatum*.

In the West Indies, *Diplodia cacaoicola* and species of *Nectria* have been recorded on the fruits and stems, but in Ceylon the fungus which may occur on both these tissues is generally spoken of as a species of *Nectria* only. In both countries the fungus, *Phytophthora omnivora*, has been recorded as growing on the fruits only.

The confusion regarding the specific identity of the parasitic fungi on cacao stems and fruits does not, however, handicap anyone concerned with the eradication of the diseases. In one or both countries the fruit disease or diseases may commence on any part of the fruit wall and eventually spread to the stem, and diseased areas on the stem may lead to the same condition in the fruit; in all cases the diseases spread very rapidly on the fruits, and quickly produce spores which are capable of being blown about by the wind. It is therefore obvious that in addition to excising diseased stem and branch tissues the fruits must be attended to and must be either destroyed when diseased, or sprayed with fungicides when in a healthy state.

Disposal of Diseased Cacao Fruits.

The fruits should be very frequently collected, on account of the rapid development of the fungus within their walls; all husks of diseased fruits should be either buried in deep holes and covered with soil, or lime and soil, or burnt on the spot. The fungi affecting the fruits can grow on dead as well as on living material, and if the husks are heaped and allowed to accumulate, the disease spreads very rapidly, and thousands of spores are produced; furthermore, one of the parasitic fungi, common to the West Indies and Ceylon, produces spores *inside* the fruits, which are only liberated when the husks are split, and it is obvious that if these are not buried or destroyed at once, much harm may result. Many persons have raised the question as to the desirability of collecting the husks and accumulating them in an open field-pen, and allowing them to rot

there with other substances, the decayed mass to be subsequently used for manure; this method of disposing of cacao husks can only be allowed when all the fruits are healthy, and if adopted on a plantation where either *Diplodia* or *Phytophthora* occurred it might assist in the spread of disease.

The Spraying of Cacao Fruits.

Spraying as a means of combating the cacao-fruit diseases has not been seriously adopted in Ceylon or the West Indies, partly on account of the difficulties experienced in obtaining suitable appliances and chemicals, and also on account of the absence of definite information as to the advantages accruing from the necessarily increased expenditure.

In almost every other fruit-growing country spraying is employed for parasitic fungi, and in agricultural literature it is usually described as one of the fundamental operations upon which permanent success in fruit culture depends.

The object of spraying is different from that of many other plant sanitation operations; when the fungi spread mainly by means of mycelium, the excision of the diseased areas or isolation by means of trenches is usually recommended; but if they spread mainly by spores which may be carried by the wind from tree to tree, spraying is perhaps the best method of treatment to adopt. In spraying, the object is to cover the parts liable to disease with some chemical which will kill the fungi from diseased areas as soon as they alight on healthy tissue; it is therefore more or less a form of plant insurance from infection.

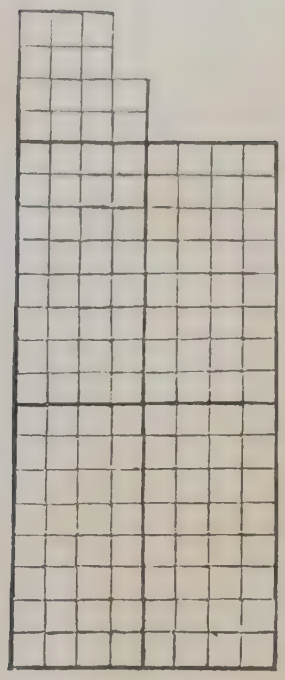
Only Fruits to be Sprayed.

Experiments have been carried out in which the stems, branches, and fruits of cacao trees were sprayed after all visible diseased areas had been excised and burnt, and others in which only the cacao fruits were sprayed. The results proved conclusively that spraying could only be advised for the fruits.

It is advisable to point out that spraying alone is not at present recommended. Spraying is advised merely during the setting of the young fruits or crop-time in order to reduce the percentage number of fungus pods and so indirectly to check the ravages of the fungus over cacao estates. The spraying of the fruits must be carried out in conjunction with the excising and burning of all parts of the stems and branches affected with disease. On some estates the areas of excision are immediately rubbed with a piece of copper sulphate, and though this practice, as at present carried out, certainly does no harm, it cannot be recommended since the treatment and therefore effects are necessarily very superficial. There is the danger that the reduction in fungus pods which sometimes follows systematic spraying may satisfy requirements for a short time, but in the interests of the estates the stems and branches which bear the fruit must be periodically inspected and cankered tissue excised.

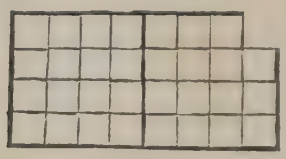
THE DECLINE IN PERCENTAGE OF FUNGUS FRUITS (1 TO 3).

1.



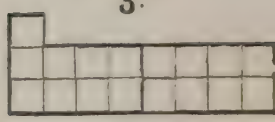
1902
35·5 %

2.



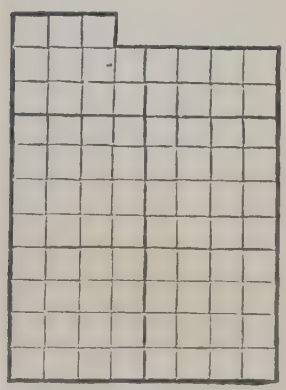
1903
7·7 %

3.



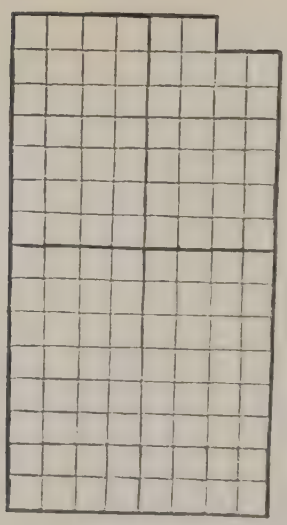
1904
4·3 %

THE INCREASE IN CROP (4 TO 6).



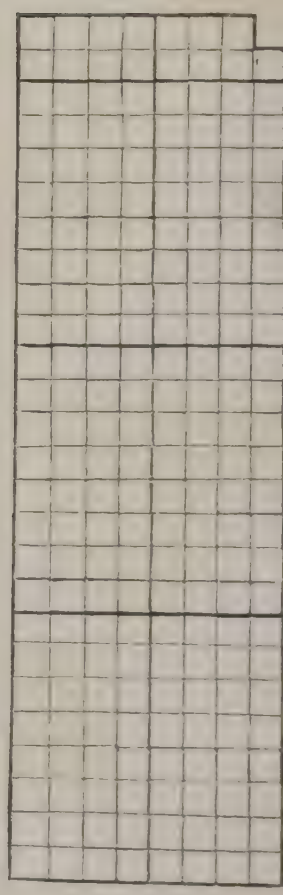
1902
0·83 cwt.
Per acre.

5.



1903
1·18 cwt.
Per acre.

6.



1904
2·07 cwt.
Per acre.

CACAO DISEASES: CURATIVE METHODS AND RESULTS OBTAINED.

Number of Diseased Fruits.

The cropping period is only too frequently coincident with our wettest months, when the conditions for the spread of the fungus on the pods are more favourable. If a check can be put on the spread of the disease at this period a considerable saving in future canker work is effected.

The necessity for spraying the fruits is apparent when one considers the number of cacao pods which are annually attacked by the fungus on ordinary cacao estates.

Proportion of Fungus and Other Fruits at Peradeniya.

Year.	Fungus.	Good.	Dried.
1902	88,765	141,272	350,144
1903	20,805	213,389	288,205
1904	19,350	380,391	169,179
1905	17,198	677,379	504,629

Monthly Percentage of Fungus Fruits.

	1905.	1904.	1903.	1902.
	per cent.	per cent.	per cent.	per cent.
January	1·1	1·3	2·2	—
February	1·3	1·3	2·4	—
March	1·7	1·1	2·6	—
April	1·2	0·5	0·9	—
May	1·5	0·6	1·7	13
June	1·1	7·5	2·9	25
July	4·2	21·0	4·0	60
August	12·3	27·4	3·2	62
September.. ...	6·7	7·7	13·7	60
October	4·5	4·5	22·8	34
November... ...	1·3	7·2	9·3	28
December	2·3	3·5	4·5	24
Yearly Average ...	2·3	4·3	7·7	35·5

Most planters will probably believe that their number of fungus pods is not so large, but if the fruits were counted the results would perhaps occasion some surprise. If the same or a much reduced proportion of fungus pods were to occur on most cacao estates of 500 acres in extent and giving 3cwt. per acre, the number of fungus pods, calculating on a 10 per cent. basis, would be over a quarter of a million per year. We know that the fungus grows very rapidly on the fruit, that a diseased fruit may be a source of infection for the stem through the mycelium alone, and that fungus cacao cannot be usually valued at more than 10 shillings per cwt.

Objects in Spraying.

In most fruit-spraying experiments the primary object is to save the fruit, but the beneficial effects cannot be measured from a single year's crop. Every cacao grower believes canker may enter the stem through the stalk of a diseased fruit. The cropping periods are the most critical of the year, as the increased surface offered by three million fruits on a 500-acre estate is bound to lead to the attachment and subsequent germination of fungus spores carried by the wind. Hence the more one sprays the more the ravages of the fungus are checked and the less the required expense in future excision work. There is another somewhat small advantage, and that is in the spreading of the fungicide to parts of the stem, providing the areas in the stem possessing living mycelium are not thereby obscured. A coating of copper compounds on the stem will kill the germinating spores of the fungus, though it does not affect the deep-seated mycelium in the tissues of the stem. For these reasons, therefore, the cost of spraying may economically exceed the actual saving of black cacao for the year during which spraying is carried out.

It should be remembered that even if disease has not appeared the value of spraying is not lost, and most planters whose estates have suffered through this fungus will agree that prevention is decidedly better than cure. The separated spores of the fungus are not visible to the naked eye, and are blown about by the wind from tree to tree. If they alight on a sprayed part of a tree the fungus is poisoned before the mycelium can penetrate into the living tissues of the pod.

When to Spray.

The fruits should be lightly sprayed on successive occasions during moderately dry weather. Experience has taught us that the best results are obtained by first spraying the young pods just after they have set. In the Peradeniya district where the months for flower production are April to June, the young pods set in August and September, and it is during the latter period that spraying can best be carried out. Several kinds of sprayers can be used, but on most cacao estates in Ceylon it is almost essential that the sprayer should be one which can be carried on the back of a cooly. The jet used should be as fine as possible, as otherwise there is considerable waste of the mixture. It is only necessary to lightly spray the fruits The mixture which goes on to the leaves is practically wasted.

Fungicides to use.

In the selection of fungicides one finds that though there are many compounds recommended in other countries as powerful poisons to parasitic fungi which attack cultivated fruits, yet only two or three can be obtained in sufficient quantity and at favourable rates from local sources. Compounds of iron, particularly the sulphate and the chloride, have been used for fungicidal purpose, but not with great success.

A mixture of flower of sulphur and lime has also been reported as being valuable as a fungicide.

It is, however, generally admitted that compounds of copper are the best fungicides as regards cheapness and efficiency. The most important are sulphate of copper, carbonate of copper, acetate or "Verdet," and copper chloride.

One or other of these compounds is used as the essential part of fungicides supplied to the public under the names of Vermorite, which essentially contains acetate of copper; Bordeaux mixture, composed originally of sulphate of copper and lime; Soda-Bordeaux, David's Powder, &c.

Copper Sulphate and Lime.—I have never used Vermorite or commercial Bordeaux mixture on a large scale, but have preferred to mix the fresh materials, using 6 lb. of sulphate of copper, and 4 lb. of lime, to 45 gallons of water. This mixture has been used because of its cheapness and the ease with which one can vary the proportions according to requirements. Any cooly can attend to the mixing. In wet districts the mixture should be so made that it will adhere to the pods, and the addition of a little more lime or mud increases the adhesive power as required. It is also recommended by some experts to add molasses, soft soap, acetic acid or vinegar to the mixture in order to increase its adhesive power. When acetic acid or vinegar is added certain copper compounds are ultimately formed which are insoluble in water. It remains to be proved whether castor oil, which is easily obtained from the seeds of the wild uncultivated plants, or the waste product from the cacao fermenting tanks, cannot be used for the same purpose. The copper sulphate and lime are dissolved separately in water, and, after mixing, the amount is made up to 45 gallons. On large estates it may prove advantageous to have a stock solution of copper sulphate and lime water. Stock solution should not be kept in iron or tin vessels on account of its corroding action, but wooden, earthen, or brass receptacles can be used. When the ingredients are mixed in the above proportions the mixture is known as the "Normal" or 1·6 per cent. Bordeaux. It is asserted that this preparation is not a very safe one to use except in dry seasons or in districts where the rainfall and dew are but slight. In the presence of much water the mixture is reported to be injurious to foliage and fruit. These disadvantages are perhaps negligible when dealing with cacao, as the fruits only are sprayed and plucked at frequent intervals.

In certain text books it is described as injurious to the delicate foliage of some fruit trees, and in one case its use is not recommended for ripening fruits. This may in some instances be true for fruit trees in temperate climates, but the leaves of cacao trees are very hardy and bad effects have not yet been observed.

Spraying Machines.

In spraying experiments the instrument used to greatest advantage varies according to the habit of the plants sprayed and the fungicide or insecticide used. It is necessary in the first instance whenever copper sulphate is the principal compound of the mixture used that the sprayer be made of metal which will not corrode through the action of copper. Iron sprayers soon become perforated, whereas those made of copper or hard brass do not become useless so quickly. The following is a brief account of the action of some of the sprayers which have been tried at Peradeniya.

Invicta Sprayer.—This is in the form of a cylinder, of capacity about three gallons, and can be carried on a cooly's back with ease. The fungicide is forced into the cylinder under pressure, a maximum pressure of four atmospheres being obtainable; the material is emitted at a rapid rate, and may be sprayed over a large area or concentrated on to special pods by the use of different-sized jets.

The cylinder, once filled up to a certain pressure, will emit a good continuous spray for 14, 33, 48, and 60 minutes with the coarse, one-rimmed, two-rimmed, and three-rimmed jets respectively. The construction of this sprayer is such that it cannot be used for the fungicide in question for the desired length of time, and certain improvements will have to be made before it can be recommended for mixtures containing copper compounds. It is, however, very useful for other purposes. These are supplied by Messrs. L. Lumley and Co., London.

The Triumph Sprayer.—This, like the Invicta sprayer, is constructed so as to allow one to force the liquid into a cylinder under pressure. The material is of such a nature that it will not corrode with copper compounds, and is therefore suitable for work in connection with the cacao fungus. The flash tube is of variable length; there is no nozzle and a single detachable jet is supplied. The cylinder once filled will continue to emit a suitable spray for 40 to 50 minutes. The pumps are made of copper, but only one is needed for every ten sprayers. Messrs. Brown & Davidson, Talawakele, Ceylon, are supplying these.

In practice the cylinder requires refilling every 40 to 60 minutes or about seven to eight times in a working day. The number of trees which can be sprayed for each filling of the cylinder depends upon the number of pods to be sprayed, and on our plots ranged from fifty to eighty; this roughly works out at two to three acres per day per cooly.

The great advantage of these sprayers is that the full pressure can be obtained at the beginning, there is no need for repeatedly working up the pressure, and the liquid continues to issue until the cylinder is quite empty. This enables the cooly, when once the sprayer is filled, to confine his attention to directing the spray and turning the tap off and on as required.

Photo by H. F. Macmillan.

SPRAYING CACAO FRUITS.

Eclair Knapsack Sprayer.—A specimen was kindly forwarded for trial by Mr. James Martin, Yatawatta, Matale, Ceylon.

This differs from the "Invicta" and "Triumph" in that after the liquid has been placed in the cylinder, the cooly by means of a handle works the pressure up until a suitable spray is obtained. As the spray issues the pressure falls, and in order to maintain the necessary pressure the handle has to be repeatedly worked. This does not allow the same amount of freedom to the cooly, and in the long run I think it involves a greater expenditure of energy. It is, however, made of thin copper which makes it more suitable for use in spraying copper-compounds. Nozzles of various sizes are supplied for use with this sprayer. In using this machine the pressure goes down so quickly that two coolies are really required per spraying machine, one to pump and the other to direct the spray and taps. When the sprayer is once filled and medium pressure continuously maintained the jets continue to issue for the following periods of time: coarse jet 12 minutes; two-rimmed jet 14 minutes; three-rimmed jet 14 minutes; one thick rimmed jet 15 minutes; one thin-rimmed jet 15 minutes. The bores of the nozzles sent with this sprayer are larger than those used with "Invicta" or Triumph" and are less suitable for concentrating the spray on to individual or groups of pods.

The "Deming" Sprayer.—This differs from the *"Eclair"* in that the handle, by means of which the pressure is maintained, is brought forward over the shoulder of the cooly, and thus greatly assists the latter in his work. The machine is supplied with an excellent single jet, which is constructed so that a spray of variable length and width can be obtained by turning in one direction. Once the desired spray has been obtained the jet can be clamped. Obviously, since the receptacle for the liquid is made of copper, and the jet is so much under simple control, this machine can be used for purposes other than those here discussed. They are supplied by the Deming Company, Salem, Ohio, U.S.A.

Results Obtained by Spraying.

Many experiments have been carried out at the Experiment Station, Peradeniya and the results obtained will be of general interest. The first series of experiments proved that the number of fungus pods could be reduced from 29 per cent. to 8 to 15 per cent. within three months from commencing spraying. The second series of experiments proved that the fungus pods can be reduced from 7·2 per cent. to 1·4 and 4·2 per cent. It was further obvious that the spraying checked the spread of cacao disease generally, and thus led to a diminished expenditure in the subsequent excision of cankered tissue on the stems and branches. Again, the experiments have shown that if the fungicide is applied when the pods have just begun to set, the immature fruits go through life with the minimum liability to suffer from the cacao disease. Thousands of young pods which set in the wet months of July and August are attacked by the fungus, and shrivel up without producing any seed.

If this young setting crop can be saved, the increase in yield will much more than pay for all the expenditure involved.

Returns from Sprayed Plots.

Plot.	Good Pods.	Fungus.	Percentage of Fungus Pods.	
43	19,789	296	1·4	
44	15,757	321	1·9	
34	6,605	203	2·9	
35	6,117	179	2·8	
36	4,317	193	4·2	
33	2,940	231	7·2	Control : not sprayed.

The above figures show that it is possible to reduce the fungus pods to a very low percentage in nearly every case. On an estate of 500 acres, yielding 3 cwt. per acre and having only 7·2 per cent. fungus pods, we find that if no spraying is done the black pods will number 216,000, whereas if the estate is sprayed as effectively as in plots 43, 44, 34, 35, or 36, the fungus pods would be only 42,000, 57,000, 87,000, 84,000, 126,000 respectively. The number of pods thus saved would vary from 90,000 to 174,000, the majority of which would probably develop to mature cacao.

Comparison Between Costs and Immediate Returns.

The question of costs and immediate returns must be considered It is encouraging to realise that, without considering the increase of crop due to young pods being free from the attacks of the fungus or the general check to the spread of the fungus, one can recommend spraying from the fact that the work will nearly pay for itself in improved quality of the cacao collected for the season during which spraying is carried out. Calculating on the assumption that good and black cacao sell at 75*s*. and 40*s*. per cwt. respectively, and that about 2,000 fruits provide seed equal to 1 cwt. of cured cacao, we obtain the following results. Plot 43 gave a total number of 20,085 mature pods, which would have contained if unsprayed, as per control plot at 7·2 per cent., no less than 1,446 fungus pods; the number of fungus pods was, however, reduced by spraying to 296, thus saving 1,150 pods, which at the difference in price gives a saving of Rs. 15 for the crop in question. The total cost for the spraying work on plot 43 was Rs. 17·04, the experiment almost paying for itself in the improved quality of the crop for that season.

The following table shows the relationship between costs and returns in each experiment :—

Plot No.	Number of Fungus Pods if unsprayed, as per Control Plot 33.	Actual Number of Fungus Pods collected.	Increase in Value of cacao collected. Rs. c.	Cost of spraying. Rs. c.
43	1,446	296	15 0	17 4
44	1,157	321	10 0	17 47
34	490	203	4 0	2 20
35	453	179	3 40	3 34
36	324	193	1 50	5 87

During wet months, when the fungus pods are numerous on the unsprayed plots, it is a pleasure to see the cacao collected from the plots under treatment. The pods from the sprayed plots are always distinguished by the small number of dried pods, larger crops, and by only 1 to 3 per cent. of fungus pods.

Fruit Pests in Ceylon.

Insects.—*Helopeltis* does considerable harm when it attacks young fruits, as the latter become more or less covered with hard plates of corky tissue, and are often contorted in shape; fruits which are nearly ripe do not suffer as much as the younger ones, but in both cases the size and quality of the seeds are affected. Green states that this pest appears to be at its worst in December-January and least harmful in August, a periodicity which may be correlated with the rainfall. The insect is supposed to be most active in the early morning, and very often coolies catch as many as 500 insects each before 9 A.M.; frequently morning coolies, provided with sticks with a sticky substance, were not able to secure such large numbers. Cacao which is not shaded is sometimes liable to suffer more than when densely shaded. *Helopeltis* was first noticed on cacao in Ceylon in 1863, and for a few years kept the progress of the cacao industry in check. The insect produces dark specks in the fruit-wall wherever it has been operating, eggs are deposited, and the effects are easily recognised. It also punctures the foliage. The same insect attacks tea, and not cacao, in some districts; sometimes only the tea is affected, at other times only the cacao fruits and leaves.

Spraying experiments have been carried out at the Experiment Station, Peradeniya, in connection with *Helopeltis* on cacao pods. It is difficult to accurately estimate the number of insects which were killed, and my only account is given in the relation of pods unaffected and affected by means of this insect. Plot 8 was treated with a solution of sulphur, and plot 7 with Macdougal's mixture. The former did very little (if any) good, and the latter mixture did not effect the good results which might be anticipated from it. Macdougal's mixture was applied from 6 to 11 A.M. each day. Though the results obtained were negative ones, it should not be concluded that the mixtures applied were useless.

Record of Helopeltis Experiments.

Plot Number.	Treatment.	Number of Pods. Helopeltis.
7 ...	Macdougal's ...	2,315
8 ...	Sulphur	2,028
9 ...	Nil	1,679

Green records that in one collection of *Helopeltis* insects, a few examples of a Reduviid Bug were found, and he suggested that they might prey upon the *Helopeltis* insects.

Green records that pod borers, known as *Myelois pectinicornella* and *Dichocrocis punctiferalis*, Guen, sometimes attack the young and medium-sized fruits. An injection of kerosene into the hole made by the borer is often effective in killing the larvæ.

Thrips produces a rusty or mahogany-coloured effect on the walls of cacao fruits in the West Indies. Beetles have also been observed by Green to feed on the outside of cacao fruits.

Leaf Diseases.

Leaf Diseases.—Black blight and scale insects are frequently found on the leaves of cacao plants and associated trees. The leaves have a sooty appearance, due to the presence of a fungus (*Capnodium*) feeding on the excrement of scale insects. Hudson states that this mixed pest is becoming very prominent in St. Lucia and Grenada, and recommends that all infected tissues should be pruned and burnt and that in planting shade and shelter trees in future only those such as *Hevea brasiliensis*, *Erythrina indica*, *Inga dulcis*, and *Inga vera*, which are immune from these pests should be used.

Leaf Diseases in Ceylon.

Insects.—Green* has recorded the appearance of Thrips on cacao leaves in Ceylon, the symptoms of attack being a yellowish blotchy appearance on the upper, and a brownish discolouration on the under, surface of the leaves, together with a deposition of the excreta of the insect; the leaves of cacao trees grown under dense shade appear to be less affected by this pest than those in exposed situations. The pest is described as being most destructive from August to November, and Green recommends spraying with Macdougal's mixture as a means of keeping it in check.

Black cockchafers, identified as *Apogonia rauca*, Fabr., and the caterpillars of *Parasa lepida*, are recorded by Green as pests which defoliate cacao plants. Caseworms (*Psyche albipes*) also riddle the leaves of cacao plants, and affected sections should be sprayed with Paris green.

Helopeltis, in addition to attacking fruits, has also been observed by Green† to do considerable damage to young shoots, by repeatedly puncturing the growing points; the young shoots die back and this change gradually extends to the larger branches. The affected parts should be destroyed. Green suggests that the isolation of individual blocks of cacao by belts of trees might be useful in checking the spread of such pests.

* Administration Report. R. B. G., Peradeniya, 1901.

† " " " " 1902.

According to Green "there appear to be three physiological but structurally identical varieties of *Helopeltis antonii:* the well-known tea pest, the cacao fruit pest, and the variety that is now causing such serious injury to the cacao tree. In the Peradeniya district the fruits are badly affected, but the cacao shoots are untouched, and the tea is almost, if not quite, free from the pest. On another estate the tea is untouched: the cacao fruits have been affected for years; and only recently has the pest turned its attention to the cacao shoots."

The leaves of cacao trees in Guadeloupe* have been observed to be attacked by an insect which riddles the foliage with minute punctures. According to Elot the disease spreads very rapidly, and often does considerable damage. Giard identified the insect as a Thrips and named it *Physopus rubrocincta*. Affected leaves soon lose their green colour, the surface becomes speckled with yellowish spots, and ultimately the foliage withers and dies. The insect seems to thrive best in low-lying lands and during the rainy season. Good cultivation and spraying with a mixture of water, soap, and kerosene oil are recommended for checking the ravages of this pest. Dr. Uzel is of the opinion that the Thrips in question should be placed in a new genus, near *Heliothryis*, and suggests the name *Brachythrips* for the genus

Root Diseases.

Fungi.—According to Morris† and Howard the root fungus on cacao trees in the West Indies is probably a species of *Polyporus* somewhat similar to that attacking the roots of forest trees in Europe. Judging from the description of the character of the mycelium and its distribution in the West Indies, as given by Howard, one is inclined to believe the fungus to be allied to the *Fomes semitostus* so common on dead stumps of trees and the roots of cultivated plants in Ceylon. When these root diseases arise, isolation of the affected trees by means of trenches, three or four feet deep, is usually the only means of protecting the adjacent trees: the stumps of affected trees might also be uprooted and burnt.

C. A. Barber, in his report on the cacao in Dominica for 1892-3, pointed out that the cacao trees were affected by a root disease similar to that known in Jamaica, and that the fungus spread underground from the roots of other trees to those of the cacao.

Hymenochæte,‡ which attack the roots of *Hevea brasiliensis*, have also been occasionally found parasitic on cacao roots.

Leaves and Fruits.

Thrips has been recorded on the leaves and fruits in the West Indies§; though the damage done is frequently insignificant. When

* Un nouvel ennemi du cacaoyer, by Aug. Elot, Revue des Cultures Coloniales, December, 1901.

† Bull. Mics. Inf., Trinidad, August, 1901.

‡ Administration Report, R.B.G., Peradeniya, 1905.

§ Insect Attack on Cacao Trees in Grenada, Bull. Trinidad, May, 1901, by H. Maxwell-Lefroy.

the fruits have been very badly attacked they become very rusty on the surface, and are said not to reach maturity. Maxwell-Lefroy is of the opinion that weak cacao plants are more liable to suffer from the attacks of "Thrips" than strong healthy ones. Spraying the fruits which are badly affected with rosin wash, kerosine emulsion, or whale oil soap is said to be effective.

Stems and Leaves.

Thread Blight.—This disease is not frequently met with on cacao trees, though it is widely distributed in the tropics, and is of a dangerous character. It has been recorded from St. Lucia in the West Indies,* where it is described as running along the branches and young twigs and destroying all parts on which it gets a firm hold. The fungus appears as dark-brown strands closely attached to the bark of the stem or branch, and can only be removed by destruction of the affected parts: the strands branch and spread irregularly and lose their white colour and add to their thickness with age. The fungus attacks leaves in the mature and bud state and is, in the opinion of Lewton-Brain, a very serious disease and one necessitating prompt destruction of all affected parts.

In Ceylon, Petch † has found it growing on nutmeg trees in association with "horsehair blight." In India a "thread blight" is commonly found on tea where it is known as *Stilbum manum*.

Pest of Dried Cacao.

The dried cacao is often infested with the larva of a Pyralid moth (*Ephestia cautella*, Wlk.,), a common pest in store-rooms. The larvæ appear to eat the epidermis of the cotyledons and to leave the greater part of the substance of the embryo untouched; the radicle is often superficially damaged and the germinating capacity entirely destroyed. Green ‡ records that on breaking open a seed from which the moth had emerged, the spaces and fissures seemed to be filled with a mass of excreta, thereby appreciably lowering the value of the produce though the cotyledons may not have been affected.

General Pests.

According to M. J. Ritzema Bos § the "krullotenplaag" or "witches' brooms" exists on cacao in Surinam and other places. It is a malformation found on various cultivated and forest trees in many parts of the world, and is known by the Dutch names "krullotenplaag", "heksenbezems" or "heksennesten", by the German names "hexenbesen" or "donnerbesen", the English witches' brooms", "witches' besoms" or "birds' nests", and in French as "Balais de Sorcières". The malformation is, according to some authorities, caused either by an insect (*Phytoptus*), by a fungus belonging to the *Uredineae*, or most frequently by the fungus

* Reports, St. Lucia, 1904 -05.
† T. Petch, Tropical Agriculturist and Mag. C.A.S., April 1906.
‡ Administration Report, R.B.G., Peradeniya, 1903.
§ Journal D' Agriculture Tropicale, September, 1901.

known as *Exoascus theobromæ*. The first sign of its presence is the production of abnormal branches often of a considerable size; ultimately a bundle of convoluted succulent branches are formed and it is doubted by many whether this disease alone will kill out a healthy cacao tree. The fungus fructifies on the leaves of the monstrosity and it is necessary that these should be destroyed. The affected areas can be pruned and the whole of the material burnt; concerted action on all affected estates is necessary for success. The Consular Report for 1906 points out that the disease still continues in Surinam, and was the cause of the poor crop recently harvested in that country. Species of *Loranthus* and *Cuscuta* often occur on cacao trees, but they can easily be removed and burnt.

Rats are reported to do considerable damage in Samoa and many other places; poisoned bait or tins placed round the tree stems are found to be effective remedial measures.

Squirrels often do a considerable amount of damage by making a hole in the fruit wall and scattering the seeds; the seeds can, however, be sold as black cacao. The number of squirrel fruits from a cacao property of known acreage is given below:—

Year.	Acreage.	Number of Fruits.	
		Squirrel fruits.	Good fruits.
1902 ...	150 acres	19,379	141,272
1903 ...	116 ,,	33,981	213,389
1804 ...	116 ,,	40,077	380,891
1905 ...	100 ,,	24,226	677,379
Total ...	582 acres	117,663	1,412,931

The total number of squirrel pods was therefore 117,663 in four years, equal to about 50 to 60 cwt. of cured cacao from about 120 acres, or approximately nine per cent of the good fruits. To supply watchers with guns seems to be the only effective step to take.

Lichens on Cacao.—Several lichens occur on the stems and branches of cacao trees, the chief being *Physcia speciosa* characterised with a light bluish thallus and black fruit; others are *Ramelinia* with a dark green thallus, and *Lecania* with a variegated thallus. Lichens are only epiphytic and not parasitic on the cacao trees and though they may harbour spores, keep the stems damp and cold, and sometimes interfere with free bud development, they do not live by extracting food materials from the plant on which they are fixed. Each lichen consists of two plants, a fungus and an algae, living on symbiotic principles; they can thrive just as well on bare smooth rocks as on cacao stems At the same time they do no good to the cacao trees and may be removed if this can be done without incurring great expense.

CHAPTER XVI

EXPORTS, IMPORTS, AND USES OF CACAO.

Imports and Exports.

THE rapidity with which the cacao industry has developed in certain tropical countries shows how easily an increased demand may be met; some countries, which a few years ago were not known in the cacao world, now export considerably over a million pounds of cured material annually, and the comparative ease with which new plantations may be brought into bearing in three or four years' time should not be lost sight of. Cacao cultivation is extending in many tropical areas, and the success attendant upon its association with trees which yield rubber of commerce has led to much planting of cacao during the last two years in various parts of the Indo-Malayan region and the West Indian islands. At the present time cacao as a single product does not appear to offer as much attraction to capitalists as other and newer products; this is due to the low prices which have ruled for cacao during recent times, and the fear that the diseases of the cacao plant might prove unsurmountable.

It will be of interest to deal briefly with the past development of the cacao industry in various countries, and to note the main features in connection with the production and consumption of this article.

Cacao Production in 1897.

It is not necessary to go back beyond 1897, and the following figures given by Bazo, Secretary, Guayaquil Chamber of Commerce, in his paper on the cacao cultivation in Ecuador, show the world's production of cacao during that year:—

Cacao Production of the World: 1897.

	Tons.
Ecuador	22,000
Trinidad	10,000
Other British West Indies ...	9,000
Portuguese Africa	7,700
Brazil	7,500
Venezuela	6,000
Dutch Guiana	4,500
Haiti	4,000
Colombia	3,000
Ceylon	1,750
Java	1,000
Guadeloupe and Martinique ...	800
Santo Domingo	150
Niger Coast	55
French Guiana	30
Congo	5

THE WORLD'S CACAO CROPS AND CONSUMPTION: 1901-1904.

If these figures are compared with those of recent times it will be noticed that during the last few years cacao crops have been largely increased especially in Ceylon, Ecuador, Trinidad, San Domingo, the Gold Coast, and the Cameroons. The exports of cacao from countries which have only recently taken up the cultivation of this product have increased more conspicuously than those from countries where cacao has long been known.

The following table gives the approximate crops of various countries during the four years 1901-1904, as recorded in the "Gordian," the export from Ceylon being corrected according to the details obtained locally. In several instances the cacao has been previously imported from some adjacent country, but the figures give one a general idea of the cacao crops exported :—

WORLD'S CACAO CROP.

	1901.	1902.	1903.	1904.
	Tons.	Tons.	Tons.	Tons.
Ecuador	22,896	24,965	23,238	28,433
Brazil	18,323	20,370	20,738	23,160
St. Thomas	16,982	17,969	21,450	20,526
Trinidad	11,942	15,955	14,885	18,574
San Domingo	6,850	8,975	7,825	13,557
Venezuela	7,860	9,925	12,550	13,048
Grenada	4,865	5,975	6,150	6,226
Gold Coast	996	2,436	2,297	5,687
Cuba and Porto Rico ...	1,750	1,875	2,625	3,266
Ceylon	2,373	3,073	1,954	3,267
Haiti	1,950	1,994	2,175	2,531
Jamaica	1,352	1,525	1,650	1,650
Martinique and Guadeloupe ...	825	925	1,150	1,215
Dutch East Indies	1,276	889	1,458	1,140
Cameroons, Samoa, and Togo ...	528	648	805	1,109
Surinam	3,163	2,355	2,224	854
St. Lucia	765	785	800	800
Dominica	—	—	—	485
Congo Free State	—	—	—	231
Other countries	700	700	800	806

The totals given in the foregoing list are not the same as those in the original article; they have been corrected for Ceylon.

AFRICA.

The Gold Coast shows the most conspicuous increase, and every year more and more plantations are nearing maturity. According to the "Gordian" the district of Accra alone produced in 1904, 515 tons, and Lagos and Nigeria together 53 tons ; and the cacao from the former district appears to find favour on the German markets.

The following list shows how regularly the cacao industry has progressed in the Gold Coast :—

QUALITY AND VALUE OF CACAO EXPORTS FROM GOLD COAST COLONY.

Year	Quantity lb.	Value £	s.	d.
1891 ...	80 ...	4	0	0
1892 ...	240 ...	4	5	0
1893 ...	3,460 ...	93	17	10
1894 ...	20,312 ...	546	17	4
1895 ...	28,906 ...	470	11	7
1896 ...	86,854 ...	2,275	13	3
1897 ...	156,672 ...	3,195	14	7
1898 ...	414,201 ...	9,616	4	0
1899 ...	714,929 ...	16,063	19	5
1900 ...	1,200,794 ...	27,280	9	7

San Domingo shows the next largest increase in export of cacao in 1904 ; Hamburg is its principal market.

The German Colonies are also showing an increase in their cacao exports, the Cameroons, Samoa, and Togoland exporting over 1,100 tons in 1904.

ECUADOR.

Ecuador, which is said to be the largest cacao-producing country, continues to show an increase, and according to the "Gordian" the following was the amount of the crop and export, in tons, during 1904.

CACAO CROPS AND EXPORTS OF ECUADOR IN 1904.

Crop.		Exports.	
District.	Quantity. Tons.	Country.	Quantity. Tons.
Guayaquil ...	24,590	France ...	13,373
Manta ...	86	Germany ...	5,289
Bahia de Caraquez...	2,384	United States ...	4,003
Esmeraldas ...	108	Great Britain ...	2,905
Puerto Bolivar ...	1,265	Spain ...	1,921
		Holland ...	573
		Argentina ...	220
		Other Countries ...	280

From the foregoing tables it is clear that though many of the West and East Indian Islands increased their exports, several countries showed a decrease, especially Surinam and the Dutch East Indies.

CONSUMPTION OF CACAO.

Though the consumption of cacao is generally of very little importance to the cultivator in the tropics, the table given below may be of interest. It is obvious that the German and Australian consumption has increased much more rapidly than that in the

United Kingdom. It is asserted that the London market is losing ground in favour of Hamburg and New York, and many Trinidad and Ceylon firms are, for various reasons, shipping less to London than formerly.

World's Cacao Consumption.

The following table given in the "Gordian" shows the consumption of cocoa in the various countries of the world during the years 1901–04 :—

	1901.	1902.	1903.	1904.
	Tons.	Tons.	Tons.	Tons.
United States	20,665	23,120	28,508	33,159
Germany	18,410	20,601	21,491	27,101
France	17,916	19,343	20,638	21,799
United Kingdom	18,908	20,386	17,485	20,552
Holland	14,373	14,666	16,741	21,124
Switzerland	4,363	5,707	5,856	6,839
Spain	5,931	9,259	6,006	5,611
Belgium	1,865	2,277	2,767	2,792
Austria-Hungary	1,685	1,820	2,034	2,510
Russia	1,757	1,818	1,900	2,055
Denmark	762	802	1,150	996
Sweden	455	591	774	870
Canada	459	312	585	650
Australia	568	554	443	550
Italy	563	466	468	479
Norway	368	410	439	472
Portugal	100	112	136	180
Finland	25	47	61	63

Consumption in 1905.

The following was, according to "Tropical Life," the consumption, in tons, in the undermentioned countries during 1905 * :—

	1905.
Germany ...	29,188
France ...	21,425
Holland ...	18,991
United Kingdom ...	20,757
Spain ...	5,670
Austria-Hungary ...	2,628
Belgium ...	2,954
U. S. A. ...	34,621

The total consumption of cacao is gradually increasing, and from the cultivator's point of view it is to be hoped that this will continue. The following table shows the total consumption in the years 1899 to 1905 and the cultivated acreage required to supply the

* Tropical Life, London, H. Hamel Smith, February, 1906.

consumed cacao, calculated as pure plantation beans, obtainable at the rate of 2 cwt. per acre, per year.

Year.	Tons.	Acreage required.
1905 ...	136,234 ...	1,362,340 acres
1904 ...	129,375 ...	1,293,750 ,,
1903 ...	112,305 ...	1,123,050 ,,
1902 ...	106,065 ...	1,060,650 ,,
1901 ...	97,204 ...	972,040 ,,
1900 ...	90,303 ...	903,030 ,,
1899 ...	90,076 ...	900,760 ,,

The figures relative to the imports and exports, given in various journals, do not always agree with one another, but the above have been given in order to draw attention to the increased consumption in Europe and America, which is noticeable in each of the last seven years, and to the important fact that the total increase in consumption in the last seven years, 1899 to 1905, can be met with the produce from less than half-a-million acres of cultivated land.

Uses of Cacao.

The uses to which the various constituents of cured cacao seeds can be put are only too well known. It is only necessary to dwell upon the points of special interest in connection with cacao as a food or beverage and the importance of the alkaloid and fat constituents.

Alkaloids and Fat in Cacao.

Many analyses have been made by Harrison in British Guiana and by Mannich and Thom to determine the percentage of alkaloids and fats in cacao beans of different colours; the following table gives those obtained by the latter at Berlin :—

Whence.	Beans.	Alkaloid.	Fat.
		Per cent.	Per cent.
Guatemala ...	Pure white ...	0·42	43·84
Criollo of Venezuela ...	Whitish violet ...	0·592	41·03
Ecuador ...	Pure white ...	0·66	42·04
Salvador ...	White with little violet. ...	0·98	40·80
Nicaragua ...	White or light violet.	1·554	39·23

Alkaloids were present in only very minute quantities in the beans from fruits of *Theobroma bicolor*. Trinidad Calabacillo with its bitter violet beans is said to possess as much as 2·223 per cent. of alkaloids, and the Trinidad Forastero with violet beans about 1·653 per cent. Generally the white seeds appear to possess less alkaloids than the coloured or violet ones; the percentage of alkaloids and fats also exhibits some relationship to the weight of the shelled beans.

The fat which constitutes "cacao-butter" is well known, and largely used for medical and other purposes. The fatty substances may consist of olein, stearine, palmitene, laurine, and free fatty acids.

Cacao Manufacture.

Cacao is manufactured from the cured beans by a process of roasting, nibbing, and grinding, accompanied by the extraction of certain ingredients and the addition of foreign substances. The composition of the cured beans has already been given, and with it that of a typical pure manufactured cacao may be compared.

Composition of Pure Manufactured Cacao *.

	Goodfellow. Per Cent.
Cacao Butter	30·89
Theobromine	2·85
Carbohydrates	22·87
Proteids	29·73
Water	9·82
Ash	3·84

In the manufacture of cacao large quantities of fat are removed and various sugars, starches, and flavouring substances are added. The manufactured cacao is placed before the public in various grades the composition of which naturally shows considerable variation. At the request of the Planters' Association of Ceylon, the following analyses were made, and published by Hughes †; they show the composition of samples of certain grades of cacao essence.

Tables 1.

"Samples of cacao essence consisting of pure cacao from which about two-thirds of the original fat has been removed:—

	No. 1. Cadbury's	No. 2. Fry's
Price per lb.	2s. 4d	2s. 1d.
Water (lost at 212° F.) ...	3·99 ...	4·30
Fat (Cacao butter)	25·01 ...	30·70
Albuminoids & theobromine ...	22·15 ...	20·38
Mucilage, Gum, etc.... ...	9·70 ...	10·64
Glucose and dextrine ...	4·10 ...	1·36
Natural starch and digestible fibres	25·91 ...	23·76
Indigestible fibre (cellulose) ...	4·13 ...	4·46
Ash or mineral matter ...	5·06 ...	4·40
	100·00	100·00
Melting point of Fat ...	84°F ...	85°F
Containing Nitrogen ...	3·50 ...	3·22
Containing Potash	1·66 ...	1·56

Mechanical Condition; Fineness and State of Granulation.

Powder passed through sieve having 10,000 holes to the square inch ...	72·59 ...	81·78
Residue left on sieve ...	27·41 ...	18·22
	100·00	100·00

* Cacao Planting in the West Indies, Harold Hamel-Smith, London, 1901.
† Analyses of Samples of Cacao, by Hughes, London, 1899.

TABLES 2.

"Samples of Cacao Essence consisting of Cacao from which about two-thirds of the original fat has been removed and some potash salts added :—

	No. 4. Van Houten's	No. 6. Rowntree's
Price per lb. ...	3s.	2s. 9d.
Water (lost at 212° F.) ...	2·94	3·82
Fat (Cacao butter)	30·10	32·50
Albuminoids and theobromine ...	21·64	19·30
Mucilage, gum, etc ...	10·03	9·04
Glucose and dextrine ...	0·97	1·76
Natural starch and digestible fibre	21·44	21·83
Indigestible fibre (cellulose) ...	4·26	3·83
Ash or mineral matter ...	8·62	7·92
	100·00	100·00
Melting point of Fat ...	84° F.	85° F.
Containing Nitrogen ...	3·42	3·05
Containing Potash	4·49	4·24
Mechanical condition: Fineness and state of granulation. Powder passed through sieve having 10,000 holes to the square inch	57·05	62·51
Residue left on sieve ...	42·95	37·49
	100·00	100·00

TABLES 3.

Samples of Cacao mixed with other materials :—

	No. 8. Tibble's	No. 9. Epp's
	s. d.	s. d.
Price per lb.... ...	2.9	1.2
Water (lost at 212° F.) ...	5.04	4.58
Fat (Cacao butter)	27.10	26.40
Albuminoids and theobromine ...	17.53	7.27
Mucilage, gum, etc.... ...	11.86	11.82
Sugar, glucose & dextrine ...	2.34	18.53
Starch & digestible fibre ...	27.10	28.45
Indigestible fibre (cellulose) ...	5.33	1.40
Ash or mineral matter ...	6.50	1.50
	100.00	100.00
Melting point of fat	80°F	83°F
Containing Nitrogen... ...	1.77	1.55
Containing Potash	2.68	0·54
Mechanical condition : Fineness and state of granulation. Powder passed through sieve having 10,000 holes to the square inch.	76.35	42.74
Residue left on sieve. ...	23.65	57.26
	100.00	100.00

It is obvious from the analyses of Hughes that in the manufacture of cacao considerable changes are effected in the original material, and that there is a great variation in the chemical composition and food value of the different priced grades. Since these analyses were made, further changes have been effected in the manufacture of cacao, and the Agricultural Department * in the United States of America has recently issued suggestions to the effect that when certain ingredients have been added they should be specified on the labels attached to the imported cacao.

The removal of certain ingredients from, and the addition of others to, the original cured cacao, is considered necessary in order to appeal to the varied tastes of the consumers. Nevertheless, the roasted and powdered cacao kernels alone would provide a rich substance to be used, more as a food than a beverage; it is rare, however, that the kernels are thus locally used, most of the cacao being exported from the places where it is grown, or manufactured into cacao or chocolate on the spot. The fat may be extracted by making a paste of the kernels, adding boiling water and subjecting the mass to pressure between hot plates of metal; the product thus obtained can be purified by successive meltings in hot water.

Chocolate.

Chocolate consists of cacao mixed with sugary and aromatic substances; it is manufactured from cured cacao beans by processes of roasting, nibbing, and grinding similar to those used in the preparation of cocoa. A very large proportion, if not all, the original fatty constituents are retained, and consequently solidification is easily effected on cooling. If sweetened chocolate is required large quantities of sugar are added to the finely-divided pasty mass and flavouring substances added according to requirements; some samples of chocolate have been shown, by Hart, to possess 65 per cent. Small quantities of chocolate of good quality are manufactured in Ceylon, Trinidad, and elsewhere, but the raw cacao is mainly exported to Europe and America for use in the manufacture of the commercial articles. Other articles manufactured from cacao are sold as cacao powder, cocoatina, etc.

Use of the Cuticles.

It has been previously shown that the integuments of the cured cacao beans are particularly rich in potash and other mineral constituents. In parts of Ireland, Italy, and Switzerland the integuments are used for making infusions instead of tea, and in other countries are used as manure or fodder. When used as cattle or sheep food the cuticles are mixed in definite proportions with the straw, grain, etc. On the continent of America the shells are burnt and potash extracted from the ashes.

---

* Board of Trade Journal, June 7th, 1906.

Seeds for Distribution.

The seeds of cacao are of a perishable nature: for this reason they cannot be successfully sent over long distances except some contrivance is adopted to assist them in retaining their germinating capacity. When the journey only occupies a few days the seeds may be sent either in the fruit or be partially dried and despatched in boxes containing charcoal and earth. When one or two weeks are taken in transport it is doubtful whether the seeds inside the unbroken fruits will arrive at their destination in a good condition; experience with consignments from Peradeniya to Madras and Singapore has recently proved that this method is frequently unsatisfactory.

Vergues*, in the French Congo, has recently been successful in preserving the cacao seeds and seedlings in a good condition for a month, by placing them in a box containing alternating beds of fine earth and sand; germination may take place during transport, but if, on arrival, the seedlings are taken out and planted in baskets for subsequent attention in the nursery, a successful result is said to be obtained.

Fruits have recently been successfully sent, by Chalot, over long distances occupying more than one month in transit; in this case the fruits were plucked from the trees just before they were fully matured, dipped in paraffin liquefied at a low temperature, and then wrapped in paper, packed in boxes, and despatched. The fruits were opened at their destination and, according to Jumelle, the seeds when placed in earth germinated at once. Fruits can also be sent in sawdust.

A rather novel method† has recently been described for transporting young plants of rare varieties over medium distances. In this case the young plants were pricked into pots, and the latter despatched in cases; such a method, however, must be very expensive, and one requiring much care and supervision during transit.

Wardian Cases.

The majority of the cacao plants which have been sent from the Western to the Eastern tropical areas, and *vice-versa*, have been despatched in Wardian cases. Hart, who has had much experience in sending large quantities of cacao seeds to Ceylon, West Africa, Nicaragua, Europe, and America, is of the opinion that it is better to send them in light earth in Wardian cases. He personally conveyed 25,000 plants from Trinidad to Nicaragua in Wardian cases, and his belief in the latter is shared by most persons of experience.

When seeds are packed in these cases they soon germinate, and, at their destination, young plants ready for transference to nursery

* Note sur le Choix et la Préparation des Graines de Cacaoyer et sur les Precautions à Prendre pour en Assurer le Transport dans des Bonnes Conditions: Deslandes, L'Agriculture Pratique des Pays Chauds.

† Jumelle, l. c.

baskets are available. The method is somewhat expensive, but it appears to be the only one deserving of recommendation when the journey occupies a long or uncertain period.

Mr. H. F. Macmillan, Curator, Royal Botanic Gardens, Peradeniya, who has had considerable experience in packing cacao seeds for transport, informs me that for a journey of two or three weeks by post the seeds may carry safely if, when fresh from the fruits, they are spread out until the soft pulpy mass which surrounds them is partially dry, then turned over with powdered charcoal, which absorbs the external moisture of the seed covering, and packed in tins. In packing, he recommends that the seeds be arranged in layers in small tins (small empty biscuit tins are admirable for the purpose), and that a sheet of paper be put between each layer so as to prevent the packing material filtering to one side. Mr. Macmillan prefers the Wardian case-principle, when the length of the journey is uncertain and states that, "my method has been to place about four inches of fine light compost, such as leaf-mould and coir-dust, in the bottom of the Wardian case, pressing this evenly and levelling it on the surface, then sowing the seeds thickly, and covering them with a thin layer of the compost Thin bamboo twigs with the leaves stripped off are laid lengthwise on top, and across these at intervals of three inches are placed wooden battens which are held in position by two pieces nailed on longitudinally to the sides of the case. This precaution is necessary to keep the contents of the case in position during transit, and if not too thickly placed it will not interfere seriously with the growth of the seedlings. In this way at least 500 seeds can be sown in a case; and as these take about a fortnight to germinate there should be at destination a crop of fine seedling plants ready for placing into pots or other receptacles previous to planting them out. Where, however, seeds are not available, plants may be packed in Wardian cases in the usual way, but as compared with seed a case will naturally only hold a very few."

APPENDIX.

Metric and English Systems.

Throughout this book the Metric and English systems have been used; in order to enable the reader to convert one into the other, a table of useful equivalents is given below.

Temperature.

Conversion of Fahrenheit into Celsius.

°F.		°C.	
100	=	37·8	...
95	=	35·0	...
90	=	32·2	...
85	=	29·4	...
80	=	26·7	...
75	=	23·9	...
70	=	21·1	...
65	=	18·3	...
60	=	15·5	...

$t^\circ\ C = \frac{5}{9}\ (t-32)^\circ\ F.$

Example: $t^\circ\ C = \frac{5}{9}\ (400-32)^\circ\ F.$

$= \frac{5}{9} \times 368$

$= 204.5$

$\therefore 400^\circ\ F = 204.5^\circ\ C.$

Conversion of Celsius into Fahrenheit.

°C		°F	
50	=	122	...
45	=	113	...
40	=	104	...
35	=	95	...
30	=	86	...
25	=	77	...
20	=	68	...
15	=	59	...
10	=	50	...

$t^\circ F = \frac{9}{5}\ t^\circ C + 32^\circ$

$= \frac{9}{5} \times \frac{300}{1} + 32$

$= 540 + 32$

$= 572$

$\therefore 300^\circ C = 572^\circ F.$

Measurements.

One metre (m) = 39·37 inches.
One centimetre (cm) = $\frac{1}{100}$th of a metre = 0·3937 inches.
One millimetre (mm) = $\frac{1}{10}$ of a centimetre = 0·0394 inches.
One yard = 1·09 metre.
One foot = 30.48 centimetres.
One inch = 25·4 millimetres.

WEIGHTS.

One gram is the weight of one cubic centimeter of water at 4° C.

1 ounce (Avoirdupois) = 28·3495 gram.
1 pound (,,) = 453·59 ,,
1 gram = 0·5643 dram (Avoirdupois)
1 kilogram = 1,000 grams.
= 2·4 pounds (Avoirdupois)

CAPACITY.

1 Imperial quart = 1·135 litre
1 litre = 0·8811 imp. quart.

N.B. *Meter* means the same as *Metre.*

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